NUTS AND VOLTS

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JULY 2007

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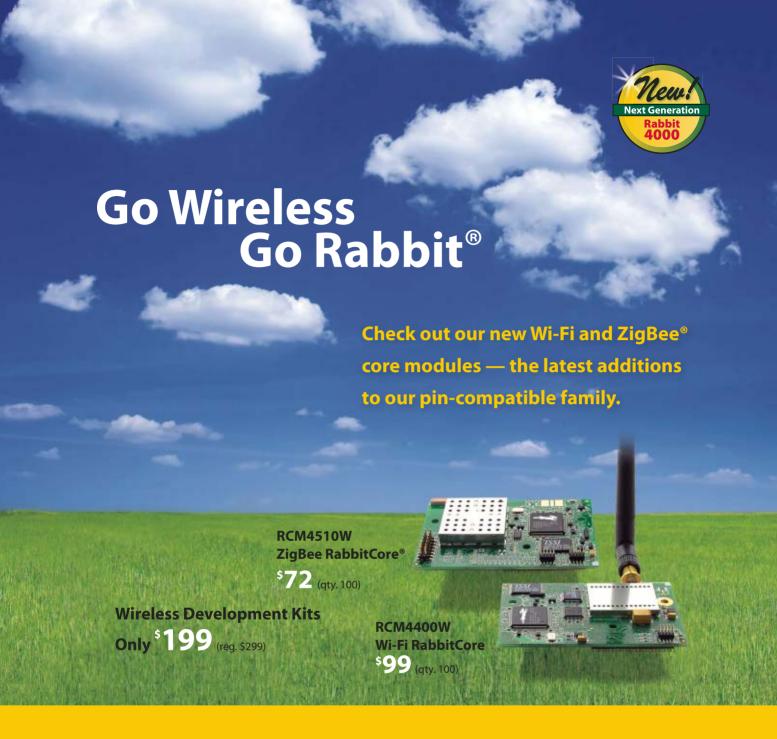From Digital Values**

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NUTS AND VOLTS

PROJECTS and FEATURES

COLUMNS

DEPARTMENTS

DEVELOPING PERSPECTIVES

by Bryan Bergeron, Editor

Do you consider yourself a competent electronics enthusiast? Competency — a measure of someone's skills, knowledge, and attitudes in a domain — is a term usually associated with work and human resource departments. However, the concept of competency also has merit in the avocation of electronics. But what constitutes competency, and why should you aspire to greater competency?

The competency required of a professional electrical engineer, pilot, or surgeon is reflected in licensing requirements established by professional organizations, typically under the auspices of a government agency. Professional competency is also suggested by awards, publications, pay, and promotions. Similarly, some avocations, such as amateur radio, have licensing requirements that reward competence. Amateur radio operators who demonstrate knowledge of electronics, operating principles, and international and national telecommunications rules on written exams are rewarded with access to additional segments of the radio frequency spectrum. Some competencies, such as the ability to send and receive Morse code at specific speeds, have been dropped from the licensing requirements.

However, there are no licensing requirements or other externally imposed criteria for what constitutes a competent electronics enthusiast, and no limitations on access to devices or technologies. So why give up the freedom of an open avocation which is limited only by your imagination? After all, unlike a parachutist or private pilot, there is little danger that someone wielding a soldering iron and a few printed circuit boards could represent a significant threat to themselves or bystanders.

I'm not advocating that the government or other organization establish licensing criteria for those who enjoy our hobby. What I am suggesting is that you make a personal commitment to establish your personal competency criteria for maximizing your enjoyment. Reasonable competency criteria include knowledge of safety, electronics theory, analog and digital components, the proper selection and use of test equipment, how to integrate components and systems, and where to obtain equipment and supplies.

The criteria suggested for this definition of competency is intentionally broad, with an emphasis on safety and integration. For example, you should know how to safely handle lead solder, as well as how to avoid or disperse the rosin fumes from lead or leadless solder. You should also know how to avoid ground loops and other sources of noise when using test equipment. Integration and practical construction techniques can be gleaned from reading construction projects, akin to case studies in many professions, but can only be mastered by hands-on experience.

Even if your interests lie primarily in, say, microprocessors, to build anything significant, you'll eventually have to develop competency in electronics beyond microprocessor development languages and environments. For example, if you decide to add GPS navigation to a robot, your knowledge of microprocessors and programming will be essential but probably not sufficient to achieve your goal. To install and debug the navigation system, you'll need a working knowledge of sensors, antennas, RF signal propagation, and mechanical design principles. Furthermore, you may require knowledge of WiFi or USB if you intend to interface the GPS receiver to a cell phone, laptop, or desktop computer.

Given the constant flow of new components and chip manufacturers, it can be daunting to stay abreast of the latest technologies and devices. But, with a little discipline and your personal curriculum, it is doable. You can start here, with this issue of *Nuts & Volts*. Before turning to your favorite regular column, take a minute to read over the table of contents, and then at least skim the articles on the technologies with which you may be unfamiliar. As you read, think of how you might use the information in your current or future project.

Supplement your reading with a hands-on project that integrates your primary interests with unfamiliar technologies. Consider keeping an informal diary of your target competencies and what you've done to develop them. You'll be rewarded with greater selfconfidence, an expanded universe of possible projects, a sense of personal growth, and good habits that will spill over into your professional life. What else could you ask for from an avocation? **NV**

READER FEEDBACK

ONCE SCHMITTEN

In Parts 1 and 2 of the subject series, Ray Marston mentions various ICs that have a Schmitt Trigger action on the gate inputs. In Part 2, he describes how the hysteresis in such a gate allows it to be used as a sine wave to square wave converter. What is missing is an explanation of why a normal gate would not suffice. I'm hopeful that in one of the forthcoming parts, Ray will expound on the reason for even having a Schmitt input available and why normal gates are unsuitable for some applications. I realize that this may have been covered in past articles, but the present series is an excellent place to remind readers of this issue.

I was recently reminded of the purpose of the Schmitt Trigger input when I interfaced an IR emitter/detector directly to a microcontroller module which has a non-Schmitt type input. This is the second time I've learned this the hard way — the first being several years ago. The output of a non-Schmitt type gate is not defined when the input is in the middle of its allowable range (typically 0-5 V). When a slowly changing signal such as a sine wave or analog signal from an IR de-tector is used as the input, the output can sometimes oscillate through several rapid cycles as the input voltage transitions from low to high. Any such oscillations will always defeat an attempt to measure pulse width or to count pulses. The remedy for this is provided by the hysteresis effect of the Schmitt Trigger input.
— **Rodney Case
Advance, NC**

RIGHT ON WITH OFF TOPIC

I was pleasantly surprised to find in the May issue the article on Sonic Realism. It seemed a bit "off topic" in a magazine devoted mainly to digital matters not applied to audio. As the saying goes, a breath of fresh air.
— **V. M. Knoll**

FIRED UP OVER AUTO IGNITIONS

Regarding the article on powering furnaces on inverters, generators, etc. ... powering furnaces with auto ignition can be tricky. They like to see a real ground and a real neutral. My new stove asked for a real ground, neutral, and a hot. I had an old feed which was not grounded. Dealer blew one board and couldn't get another working. Stove said NOT to get a ground via gas pipe. I ran a new feed at considerable trouble with full three wire specs and the stove worked. There may be something about

> The special "Green Power" section originally scheduled for the July issue has been moved to the August issue.

AS IT TURNED OUT, IMPLEMENTING THE CLAPPER INTO THE AUTOMATIC GARAGE DOOR OPENER WASN'T SUCH A GOOD IDEA AFTER ALL!!

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PIC16F677	2048	128	256	12	1/1	SPI/I²C™	PDIP, SSOP, SOIC, 4mm x 4mm QFN
PIC16F685	4096	256	256	12	2/1	ECCP+	PDIP, SSOP, SOIC, 4mm x 4mm QFN
PIC16F687	2048	128	256	12	1/1	EUSART, SPI/I²C™	PDIP, SSOP, SOIC, 4mm x 4mm QFN
PIC16F689	4096	256	256	12	1/1	EUSART, SPI/I²C™	PDIP, SSOP, SOIC, 4mm x 4mm QFN
PIC16F690	4096	256	256	12	2/1	ECCP+, EUSART, SPI/I²C™	PDIP, SSOP, SOIC, 4mm x 4mm QFN
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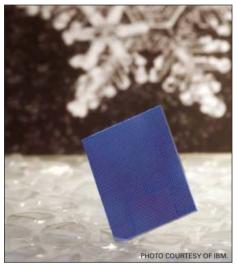
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■ BY JEFF ECKERT

ADVANCED TECHNOLOGY

AIRGAP TECHNOLOGY DEMONSTRATED

■ IBM has created experimental versions of its POWER6 microprocessor using self-assembly techniques.

PHOTO COURTESY OF IBM.

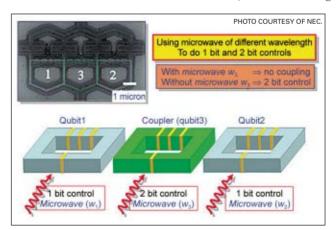IBM (**www.ibm.com**) has announced the "first-ever manufacturing application of self-assembly used to create a vacuum — the ultimate insulator — around nanowires for next-generation microprocessors." The technique mimics the pattern-creating process that nature uses to form such things as seashells, snowflakes, and tooth enamel. While it is commonly referred to as "airgap technology," the gaps are actually vacuums. Because the vacuum areas are better at providing insulation between the copper wires in the chip than insulators used in conventional manufacturing, wiring capacitance is reduced, thus producing a chip that can run 35 percent faster (or consume 15 percent less power) than today's most advanced devices.

Conventional chip manufacturing involves using a mask to create circuit patterns and etching away the unneeded material (see **www.applied materials.com/HTMAC/HTMAC_011**

207.swf if you need a basic explanation), but the new technique skips these steps. Instead, you simply pour some goop onto a silicon wafer, bake it, and let the structure assemble itself. The process creates trillions of uniform nano-scale holes across the entire 300-mm wafer surface. The holes are just 20 nm in diameter, which is about five times as small as geometries that can be produced using photolithography.

This may sound like the usual technological vision with practical applications a decade or two away but, in fact, it already can be incorporated into a standard CMOS production line without disruption or new tooling. IBM expects to be selling airgap-based servers sometime in 2009, so it looks like Moore's law is still in effect.

CONTROLLABLY COUPLED QUBITS DEMONSTRATED

■ Illustration of a two-qubit quantum circuit with tunable coupling.

Meanwhile, back in the lab, NEC Corp. (**www.nec.com**), the Japan Science and Technology Agency (JST, **www.jst.go.jp/EN/**), and the Institute of Physical and Chemical Research (RIKEN, **www.riken.go.jp**) have taken a

major step toward the realization of the elusive quantum computer. Because the operation of such a machine is based on the manipulation of the states of quantum bits (qubits), one must be able to control (1) the states of individual qubits, (2) the states of two qubits (for logic operation), and (3) the coupling between the qubits.

NEC, JST, and RIKEN have already announced success in developing a solid-state qubit and a two-qubit logic gate, and now they appear to have achieved the third objective by demonstrating the world's first quantum bit (qubit) circuit that can control the strength of coupling between qubits. Coupling is provided by a third qubit located between the two logic qubits. The coupling qubit functions as a nonlinear transformer that can switch the magnetic coupling on and off via the application of a microwave signal.

This demonstrates operational feasibility and provides a simple quantum protocol that can be used for the execution of quantum algorithms. The group plans to demonstrate a larger-scale, more elaborate computation in the "near future," aiming for the eventual realization of a practical quantum machine.

COMPUTERS AND NETWORKING
UPGRADED THINKPADS ANNOUNCED

As you no doubt recall, IBM sold off its Personal Computing

Division to the Lenovo Group (**www.lenovo.com**) in 2005, including the ThinkPad line of notebook PCs. Recently, Lenovo introduced several new models, including the R61 and T61, both 14.1-in widescreen units. They offer a new top cover roll cage for improved durability, an upgraded cooling system, enhanced wireless connectivity, and longer battery life. The machines feature Intel Centrino® and Centrino Duo processors, with the R series running at up to 1.8 GHz and the T series at 2.33 GHz. For the financially challenged, there is also a Celeron® M-based 1.6 GHz unit, the R60e. The wireless service is improved via Ultra Connect II, which reduces the effects of conductive material and LCD noise, boosts WWAN and WLAN performance, and eliminates the need for an external antenna.

Connectivity options include WWAN1 (on select ThinkPad T61 models) and WLAN with 802.11n technology, 2 GB Ethernet LAN, Bluetooth, and modem, and the company's Access Connections software helps manage wireless communications. The new models also offer a 10 percent reduction in surface temperature, a 3 dB reduction in operating noise, and up to 15 percent longer battery life. List prices start at about $1,250 for the R61 and $1,400 for the T61, but the Lenovo online store is offering them for about 10 percent less as of this writing.

HP HABLA ESPAÑOL

In response to some coat-tugging from the Hispanic community, Hewlett-Packard (**www.hp.com**) has announced two additions to the Pavilion line of desktop computers, so si usted habla español, usted tiene suerte. For a mere $329 base price, you can pick up a model a6005y, which can be customized with the Spanish versions of Windows Vista. It comes with a Spanish keyboard and optional Spanish versions of things like Norton Internet Security, Microsoft Office, and Roxio Creator. Buyers also get Spanish-language versions of the documentation. You have a choice of a Celeron® D 360 (3.46 GHz), Pentium® 4 641 (3.2 GHz), or a Pentium D 925 (3.0 GHz) processor.

If you can afford to bump it up to $599, you can get the model a1726x, which allows users to choose either English or Spanish at the set-up phase and includes multimedia keyboards for both. It comes with a 320 GB drive, 1 GB of memory, a Pentium D processor (2.8 GHz), and a CD/DVD drive with built-in label-burning capabilities to make your bootleg recordings look professional. The machines are available from HP's online store, as well as CompUSA, Costco, Office Depot, and Office Max.

SPEED KIT FOR FIREFOX

If you are among the users of the Firefox web browser (who now constitute about 15 percent of the surfing world), you should take note of Fasterfox, a free performance-enhancement package from the folks at **mozdev.org**. Among its functions are Tweak Network, which allows you to optimize a range of network settings; Block Popups, which rejects popups initiated by Flash plug-ins; and Page Load Timer, which tests the effectiveness of your settings. But most interesting is Prefetch Links. This part of the accelerator actually tracks down links from what-

PHOTO COURTESY OF MOZDEV.ORG.

■ Screenshot of the Fasterfox presets.

ever page you are viewing and quietly caches the linked pages in case you decide to go there. Then, if you click on the link, the page will already be in your machine and ready to view.

The downside is that using this feature increases the load on web servers and drives system administrators bonkers. Reportedly, some sites are beginning to detect the prefetch operations and are blocking clients that use it. But you can choose the "Courteous" setting, which gives you the system tweaks but not the prefetch. To download Fasterfox, just go to **fasterfox.mozdev.org**. If you don't already have Firefox, you can get it at **www.mozilla.org**.

CIRCUITS AND DEVICES
FILM CAP REPLACES ELECTROLYTICS

■ The Type UNL film capacitors are designed to replace electrolytics in a range of 400 to 1,500 VDC.
PHOTO COURTESY OF CORNELL DUBLIER.

Cornell Dublier Electronics (**www.cde.com**) has introduced the Type UNL power film capacitors, aimed at replacing aluminum electrolytics to provide higher current, voltage, and reliability. The devices

PHOTO COURTESY OF HEWLETT-PACKARD.

■ An HP Pavilion desktop PC with a w19e flat panel monitor.

INDUSTRY AND THE PROFESSION

ELECTRIFIED RESTAURANT FRANCHISES AVAILABLE

PHOTO COURTESY OF uWINK, INC.

■ Touch screen showing uWink food offerings.

What do you do if you are the father of the video game industry (remember Pong?), founder of Atari and Chuck E. Cheese restaurants, and looking for something else to do? Well, you blend the concepts and open a place that combines food, drinks, and digital entertainment so customers can eat, drink, and play at the same time, right at their tables. The result is Nolan Bushnell's uWink restaurants, which are now available to franchise partners.

At uWink, customers order food, drinks, and media directly from tabletop touchscreen terminals. Possibly the best part is that you don't have to play alone — you can interact with people at other tables, making it easy to deliver your lewd and lascivious proposals from a safe distance.

As of now, the only location is in Woodland Hills, CA, so you can open yours pretty much anywhere else. And if you don't want to open your own restaurant, you can still participate. uWink is a publicly-held company, with its stock selling for $1.65 per share as of this writing. For more information, visit **www.uwink.com**.

TRANSISTOR TURNS 60

PHOTO COURTESY OF BELL LABS.

■ The first transistor ever assembled.

Start planning the celebrations now, because the 60th anniversary of the transistor is coming up on December 16. Back in 1947, William Shockley, John Bardeen, and Walter Brattain put it all together at Bell Laboratories and changed electronics forever. This one was called a "point contact transistor" because it operated when two pointed contacts were pressed onto the surface of the semiconductor material. The contacts — made of gold — are supported by an insulator and separated by a few thousandths of an inch. The semiconductor material is germanium. And the rest, as they say, is history.

---

use a metallized polypropylene dielectric in a snap-in style case and provide voltages up to 1,500V, continuous currents better than 20A, and equivalent series resistances (ESRs) as low as 6 m. Although they offer lower capacitance values for an equivalent size package, the film caps are self-healing and nonpolar, and they provide up to 10 times the ripple current capability as compared to the electrolytics. The UNL devices offer capacitance ranging from 4.7 to 35 F, voltage from 400 to 1,500 VDC, and an operating temperature range of -55°C to 85°C. Typical pricing starts at $6 in quantity.

NEW EARPHONE LINE

■ The Shure SE530 Sound Isolating™ earphones.

In olden times, if you wanted clean audio and

PHOTO COURTESY OF SHURE, INC.

no distractions from the surrounding environment, it meant (a) cranking up the volume just shy of where the neighbors would call the police or (b) clamping a pair of headphones the size of Spam cans over your ears and propping your head up to avoid neck pain. The cheap little buds that you stuff into your ear openings just didn't cut it.

However, in recent years, earphones have evolved into some pretty sophisticated and effective devices, many of which slide farther back into your ear canals to provide better isolation (40 dB or so) and sound quality. Some have multiple drivers, and the pro-level ones may require you to visit an audiologist to get a custom fit. These high-end ones can run you up to $900 or more, so they are generally only for use in the studio or by truly devoted audiophiles.

Manufacturers have been focusing on more reasonably priced, consumer-oriented versions lately, and Shure (**www.shure.com**) has jumped in with four choices in its SE model lineup. At the entry level is the SE210, which gives you a single driver (per ear, of course) and a range of 25 Hz to 18.5 kHz. This model will run you about $150. At the other end of the spectrum is the SE530PTH (where the PTH means it has a push-to-hear control). For $550, you get dual woofers and a tweeter aimed at your eardrums and a range of 18 Hz to19 kHz. But be aware that using these things can be hazardous to your hearing.

Research at Northwestern University has concluded that if you run them up to 110 dB or so, you can achieve hearing loss in as little as an hour (which is one reason why I'm sticking with my 1969-vintage KLH loudspeaker system). **NV**

■ BY JON WILLIAMS

REV IT UP

FOR ME, ONE OF THE MOST EXCITING ASPECTS of working with the SX and programming it in SX/B is the ability to create accessory devices like last month's animatronics controller. With what we've learned, it seems that the next logical step is a Parallax AppMod-compatible device; since Parallax already has a great servo controller (the PSC) that uses this protocol, let's build a compatible motor driver. And for those just getting started or don't want to have a PCB etched, have no fear! We're going to whip this baby together with a handful of parts and Parallax's incredibly low-priced SX28 proto board.

Some of you probably remember an article last year where we experimented with interrupts and motor control; well, that was just scratching the surface. We've all come a long way since then, as has SX/B, and we're going to put what we've learned to work. Since the AppMod protocol uses a single wire for communications we'll have to deal with that, and while we're at it, we'll implement a baud selection input so that the device can be used with the BASIC Stamp 1 at 2400 baud, or with the BASIC Stamp 2 family at 38.4K baud. What you'll soon see is that the simplest aspect is implementing the PWM (pulse width modulation) signals that control the motor outputs (we'll control up to two motors with this device — and expanding it will be pretty easy).

As ever, we should start with the specifications. If we're going to follow the AppMod protocol, we should implement a command to return the firmware version of the device. The message is simple:

```
"!MC" {address} "V"
```

Of course, the quotes aren't actually used in the message; they're used in the line above to indicate string or ASCII character values versus numbers. The device will use a two-bit address, so valid addresses are from %00 (board 0) to %11 (board 3).

The return value for the version request is a simple three-byte string that holds the major and minor version numbers, separated by a period. Like this:

```
"0.1"
```

Again, this value is returned as a string and conversion may be required for some applications of the version number.

Now that you've got an idea of how the AppMod protocol works, here are the other commands that we'll implement:

• "G" — Get device status, returns three bytes (speed and direction bits)

• "S" — Sets the speed and direction of one or both motors, nothing returned

• "X" — Stops both motors if running, nothing returned

This is a very simple command set, and as you'll see there's a lot of room in the code for additional features if you choose to add them for your particular projects.

Like the last couple projects, this one uses the ISR to handle a lot of the tough work "in the background," including delay timing, receive and transmit UARTs, and the PWM output for the motors. You'll see that the UART code is identical to last month, the exception being that the bit delay values are loaded from variables so that we can select between the supported baud rates of 2400 and 38.4K.

Here's a little secret — a cheat if you will — that's used to keep the transmitter UART code simple: Even though we're supposed to be using open-true communications where a transmitted "1" will pull the serial line low and a transmitted "0" will allow the serial line to be released to the pull-up, this is a bit of a headache. So ... what we're going to do is put a resistor inline with the serial pin to protect connected devices in the event of an electrical conflict which, in fact, is not likely to happen as we'll mostly be using a BASIC Stamp which does support open-true communications.

Now, that said, we do need to check the state of the transmit UART before putting the device into receive mode; that's easily done by checking the variable called txCount that keeps track of the bits being sent. In addition to the transmitter check we'll also incorporate a baud selection routine and the ability to convert lower-case

letters to upper-case when needed by the command processor; this last section simplifies the mainline code.

```
FUNC RX_BYTE
  ASM
  BANK  serial
  TEST  txCount
  JNZ   RX_BYTE
  BANK  0
  ENDASM

  IF __PARAMCNT = 1 THEN
    tmpB2 = __PARAM1.0
  ELSE
    tmpB2 = 0
  ENDIF

  INPUT Sio
  IF BaudRate = BR2400 THEN
    baud1x0 = BaudSlow1x0
    baud1x5 = BaudSlow1x5
  ELSE
    baud1x0 = BaudFast1x0
    baud1x5 = BaudFast1x5
  ENDIF

  DO WHILE rxReady = No
  LOOP
  tmpB1 = rxByte
  rxReady = No

  IF tmpB2.0 = ToUpper THEN
    IF tmpB1 >= "a" THEN
      IF tmpB1 <= "z" THEN
        tmpB1.5 = 0
      ENDIF
    ENDIF
  ENDIF

  RETURN tmpB1
ENDFUNC
```

On entry to the **RX_BYTE** function, the value of *txCount* is tested to see if it's zero (not transmitting); the code will jump back to the start of **RX_BYTE** until anything currently being transmitted is finished. With the transmit buffer clear, we'll check to see if a parameter was passed; this will contain a flag (in bit 0 of the parameter) that will indicate the desire to convert a lowercase letter to uppercase. All other values will pass through unmodified.

Now it's safe to make the serial line an input and then check the baud rate jumper on the controller. The setting of the jumper handles the bit count values used for the start and data bit timing. At this point, it's a waiting game for the receive flag, *rxReady*, to go from zero to one. Once a byte comes in, we check to see if case conversion was specified and if so, whether the received byte is a lowercase letter. Conversion to uppercase is a simple matter of clearing bit 5 of the byte (the same as subtracting $20).

The transmit subroutine is a little simpler, yet also needs to check the state of the transmit buffer so that a character doesn't overrun the one currently being transmitted.

```
SUB TX_BYTE
  ASM
  BANK  serial
  TEST  txCount
  JNZ   TX_BYTE
  BANK  0
  ENDASM

  IF BaudRate = BR2400 THEN
    baud1x0 = BaudSlow1x0
  ELSE
    baud1x0 = BaudFast1x0
  ENDIF
  HIGH Sio

  ASM
  BANK  serial
  MOV   txHi, __PARAM1
  CLR   txLo
  MOV   txCount, #11
  BANK  0
  ENDASM
ENDSUB
```

When all is clear to transmit, the serial line is set high — this makes it an output and puts it into the idle state. One final note on transmitting: Occasionally, SX/B users will ask how to add extra stop bits while transmitting. When using this ISR-based transmit UART, it's easy; all you have to do is change the value of *txCount* (which also starts the UART). Normally, a value of 10 would be used for one start bit, eight data bits, and one stop bit. I chose to use 11 in this program because I will be using the BS2 most of the time and the extra stop bit gives it just a little extra time between bytes.

Alright, now that we can receive bytes from and send bytes to our host, let's look at the main loop of the program that handles host commands and requests.

To begin, we will monitor the serial stream for the device's header: "!MC." In the BASIC Stamp, we have a **WAIT** modifier for **SERIN** that doesn't exist in SX/B. That's not a problem because the functionality is very easy to code:

```
Main:
  char = RX_BYTE
  IF char <> "!" THEN Main
  char = RX_BYTE ToUpper
  IF char <> "M" THEN Main
  char = RX_BYTE ToUpper
  IF char <> "C" THEN Main
```

Yes, it really is that simple — and as you can see, uppercase conversion when needed keeps things nice and tidy. Here's what that section would look like without the uppercase conversion built into RX_BYTE:

```
Main:
  char = RX_BYTE
  IF char <> "!" THEN Main

Header2:
  char = RX_BYTE
  IF char = "m" THEN Header3
  IF char = "M" THEN Header3
  GOTO Main

Header3:
  char = RX_BYTE
  IF char = "c" THEN Check_Addr
  IF char = "C" THEN Check_Addr
  GOTO Main
```

I think you'll agree that putting the case conversion code into the RX_BYTE function is worth the effort, especially when we have a program waiting on a long string that could be upper- or lowercase.

The next step in the process is to check the board address. This architecture also allows for a "global" address of 255 that affects all boards; this is especially useful for shutting down all boards with a single command from the host:

```
Check_Addr:
  char = RX_BYTE
  IF char = CmdAll THEN
    allCall = Yes
    GOTO Get_Cmd
  ELSE
    allCall = No
  ENDIF
  addr = %00
  addr.0 = ~A0
  addr.1 = ~A1
  IF char <> addr THEN Main
```

If the received address is not global (255), then it gets compared against the jumpers. Note that we're using the internal pull-ups for these pins so the code inverts the bits to make them active high. As with the header, a mismatch causes the program to jump back to **Main** and wait for the next command.

Next up is the command processor.

```
Get_Cmd:
  char = RX_BYTE ToUpper
  IF char = "V" THEN Show_Version
  IF char = "G" THEN Get_Status
  IF char = "S" THEN Set_Motor
  IF char = "X" THEN Stop_Motors
  GOTO Main
```

Again, dirt simple which is always best in my book, especially when writing modular code that can be used across a variety of projects as this AppMod framework can be. In PBASIC, we would use **ON..GOTO** or **BRANCH**, but in SX/B, I find the IF..THEN approach cleaner. Remember that this code gets compiled to pure assembly so the resulting output is very fast — this structure is deceptively efficient.

```
Get_Cmd:
  char = RX_BYTE ToUpper
  IF char = "V" THEN Show_Version
  IF char = "G" THEN Get_Status
  IF char = "S" THEN Set_Motor
  IF char = "X" THEN Stop_Motors
  GOTO Main
```

Since the Version request uses another helpful subroutine, we'll have a look at that.

```
Show_Version:
  IF allCall = Yes THEN Main
  DELAY_MS 15
  TX_STR Rev_Code
  GOTO Main
```

Note that we check to see if the command sent contained the global address; when this is the case, we don't want to respond because it could cause conflict with other devices on the line. When the command is intended for this board it will

pause just a bit to let the host (like a BASIC Stamp 1) get ready for the serial input. After that, we can send the firmware version which is stored as a z-string in a **DATA** statement. We pass the address (resolved by the compiler from the label) to TX_STR.

```
SUB TX_STR
  tmpW1 = __WPARAM12
  DO
    READINC tmpW1, tmpB1
    IF tmpB1 = 0 THEN EXIT
    TX_BYTE tmpB1
  LOOP
  ENDSUB
```

What makes this subroutine really tick is **READINC**, a fairly new addition to SX/B that will read a byte from the specified address pointer and then automatically increment that pointer. That it works with words also keeps the subroutine very clean. This routine is in my "standard" set and I suggest it be in yours, as well.

As this project is a motor controller, let's have a look at the command that sets speed, "S." The byte that follows this command will be zero (all motors), or one or two for a specific motor. Here's the code:

```
Set_Motor:
  char = RX_BYTE
  IF char = 0 THEN
    speed1 = RX_BYTE
    tmpB1 = RX_BYTE
    dir1 = tmpB1.0
    speed2 = RX_BYTE
    tmpB1 = RX_BYTE
    dir2 = tmpB1.0
  ELSEIF char = 1 THEN
    speed1 = RX_BYTE
    tmpB1 = RX_BYTE
    dir1 = tmpB1.0
  ELSEIF char = 2 THEN
    speed2 = RX_BYTE
    tmpB1 = RX_BYTE
    dir2 = tmpB1.0
  ENDIF
  GOTO Main
```

The use of **IF-THEN-ELSEIF** allows us to check for valid values without defaulting to something that could be incorrect; look closely, there is no **ELSE** clause in the structure. For example, if a motor number of three were specified, all of the **IF** clauses would fail and neither motor would be affected. For each motor, we expect to receive speed (0 for 0%, 255 for 100%) and direction (0 for forward, 1 for reverse). The direction for each motor is encoded in bit flags so we will copy those bits from the associated bytes in the command stream.

GET YOUR MOTORS RUNNIN'

Now that we have speed and direction values in the controller, how do the motors get moved? It's actually pretty simple with a bit of accumulator-based PWM. The program keeps two values for running the motor at a given duty cycle: the speed sent by the host and an accumulator that is used to control the outputs.

On each pass through the interrupt, a variable called mTimer is incremented; this is the timer that controls motor

updates. When this value rolls over to zero, we will reload the motor accumulators with the speed values sent by the host. At this point, the motor outputs are both set to off.

Then, for each motor, the accumulator is incremented and when it rolls over to zero, the correct output (set by motor direction) is made high. So you see, the higher the motor speed setting, the more quickly the rollover to zero will happen and the longer the motor will be on as a percentage of the cycle. Hence, it will run faster. This is a neat, very efficient trick and is even easier when it's just one output to be controlled as with LED brightness, or charging an RC circuit to create an analog output.

```
Check_Motors:
  ASM
  BANK   motor
  IJNZ   mTimer, M1_Fwd
  MOV    m1Acc, speed1
  MOV    m2Acc, speed2
  MOV    MotorCtrl, #%0000

M1_Fwd:
  IJNZ   m1Acc, M2_Fwd
  JB     dir1, M1_Rev
  SETB   M1_A
  JMP    M2_Fwd

M1_Rev:
  SETB   M1_B

M2_Fwd:
  IJNZ   m2Acc, Motors_Done
  JB     dir2, M2_Rev
  SETB   M2_A
  JMP    Motors_Done

M2_Rev:
  SETB   M2_B

Motors_Done:
  BANK   0
  ENDASM
```

CONSTRUCTION NOTES

This one is easy thanks to our friends at Parallax. I used the $10 SX28 proto board and components that most of you have in your supply bins — with the possible exception of the L293D. Figure 1 shows the schematic and connections to the SX28 proto board and Figure 2 will give you an idea of what it looks like when wired up and running. Note the addition of TB1 which allows us to connect Vin to V-Motor if we want to run from the SX28

Proto Board Supply (the power switch needs to be in position 2 for this). If a separate supply is required, this should be connected between V-Motor (TB2.1) and Ground (TB2.6).
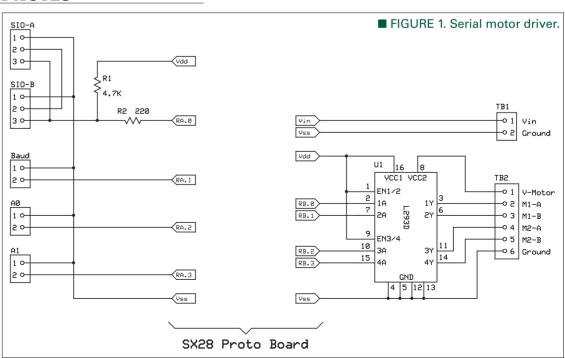
GETTING STARTED WITH THE SX

The last few articles have stirred up quite a lot of interest from those using other processors — and why not? The SX is lean, mean, and darned cool, and with SX/B there's a lot of power to be had without a gigantic cash outlay. Case in point: the SX28 proto board that I used for this project. There's not a lot of places you can get a fully-built microcontroller board with a beefy power supply and nice breadboarding space for $10. They're perfect for one-off projects, and can be real life-savers when you're pressed for time.
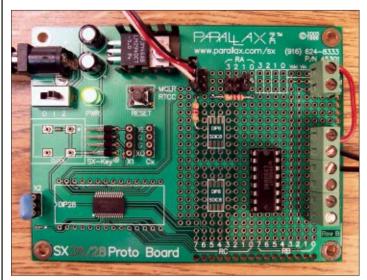
Just last summer I met with a client who wanted a custom solenoid driver for a special project. We met on a Friday afternoon, discussed the project, and reasonably concluded that it would take about two weeks to complete. Then, just as I was about to head home the client asked if I could whip up something "quick and dirty" for Monday. "Are you kidding?" I thought ... but my actual answer was, "Let me see what I can do."

In the end, of course, I hand-built a prototype using the SX28 proto board and used manual inputs (potentiometers) instead of the fancy digital display originally called for in the design. Well, the SX28 proto board (and SX/B) got me out of a bind as I was able to get the quick and dirty version going, but it also cost me a few bucks as the "quick" version worked so well that the client cancelled the rest of the contract. I guess the lesson is to keep the SX28 proto board handy for emergencies, just don't tell your customers that Parallax has done a lot of the hard work for you!

All kidding aside, the proto boards (there's one for the SX48, as well) are probably the least expensive way to get started with the SX — after you get a programming tool. For

■ FIGURE 1. Serial motor driver.
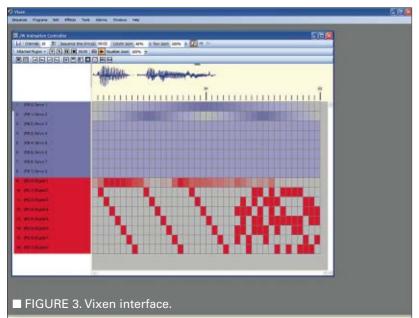
■ FIGURE 2. Completed motor controller.

programming, you have two choices: the SX-Key and the SX-Blitz. I always recommend the Key because it lets you tap into all the power of the IDE, including debugging. The Blitz is purely a programming device; if you're really on a budget, then this will work. Many Blitz users have found Guenther Daubach's SX-Sim a great tool for stepping through code when things aren't working quite right. If you can save a few pennies for the SX-Key, I can promise you it will be worth it.

SX/B 2.0?

You may have noticed a slightly different format to subroutines and functions: specifically, they begin with **SUB** or **FUNC**, and end with **ENDSUB** or **ENDFUNC**. This is not a requirement of the current compiler (version 1.51.03) but it is a good habit to get into so that your code will be compatible with SX/B version 2.0 which is scheduled to be released later this year. I'm told it will include local variables

■ FIGURE 3. Vixen interface.

and is designed to make multitasking programs easier to create — it should be very cool!

ANIMATRONICS CONTROLLER UPDATE

The May article generated an enormous amount of feedback — even one piece of quasi "hate mail" (thank you, anonymous emailer, for making me laugh out loud). I think showing a framework for servo control is really exciting a lot of folks as we use them in so many places (e.g., robotics).

There are two issues I want to address: First, I made a mistake in the regulator I specified — forgive me a small bit of laziness; I had used that regulator (LF50CP) in a previous project but neglected to go back and check its specs for this one. As one kind reader pointed out, that regulator is only good for 0.5A and that might not be sufficient when running up to eight servos as the board is designed to do. If you're planning to build that board, use the LM2940-5.0 (Digi-Key LM2940CT-5.0-ND) or the L4940V5 (Mouser 511-L4940V5) and put a heatsink on it if you're going to control more than a few servos.

The other issue I want to address is device control. In May, I talked about developing a program that would let me synchronize the servo and digital outputs with an audio track — this generated more mail than most columns and I appreciate all the great suggestions. That said, I've put my personal development plans on hold.

What? You see, in doing research on AC lamp dimming (something we'll work with in November), I came across this really neat piece of freeware called Vixen (Figure 3) and my new best friend is Vixen's developer, KC Oaks. Vixen is tremendously popular with amateur — and I dare say professional — Christmas lighting enthusiasts. Vixen does what I need: it allows me to synchronize outputs to an audio track (and that's just scratching the surface).

One of Vixen's many strengths is its open architecture. KC designed the program so that custom hardware drivers could be written and installed allowing users to control just about anything — including my animatronics controller. I speculated that I could convert the 0% to 100% lighting output on eight channels to servo positions and send the packet like I did with the little VB program. I contacted KC, he whipped up a driver, and *cha-ching* — it works! After working with it a bit, we added some refinements as shown by the driver setup dialog in Figure 4.

The JWAC (Jon Williams Animatronics Controller) setup dialog lets us select the serial port, baud rate (in case you change your SX firmware), and control settings for the servo (analog) and digital outputs. The threshold value is what gets used to convert the levels in the digital channels (8–16) to an on-off bit. You could, for example, use the Waveform add-in to set event levels on a channel such that they follow the envelope of your audio track. With the threshold setting, you could determine the audio level that

■ **FIGURE 4. AC driver setup dialog.**

turns on an output, causing the output to flash in sync with audio volume changes. The analog levels allow you to adjust for servo output range; the default values of 100 and 200 correspond to standard servo control pulse values of 1.0 and 2.0 milliseconds. The minimum setting lets you adjust that end down to 50 (0.5 ms) and the maximum setting lets you adjust that end up to 250 (2.5 ms). This should provide the flexibility required for a wide range of servos.
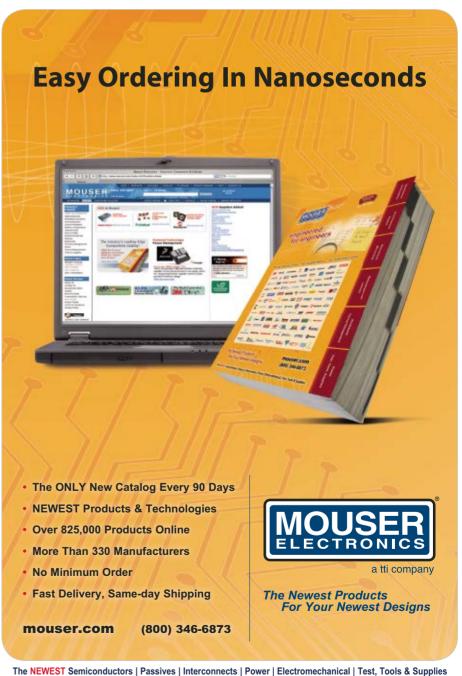
Be sure to visit the Vixen website for updates, add-ins, and to participate in their [very active] user forums. And for those of you who have the USB version of the PSC (Parallax Servo Controller), there is a driver in the works for it, as well.

Just to see how much fun a PC-driven animatronics project can be, pop on over to Peter Montgomery's website at **www.socalhalloween.com** to find out. Peter created custom software and controllers (the servo controller uses an SX28) to run his display, and yet there's no reason you can't create something similar with Vixen, a bit of skill, artistic talent, and a whole lot of patience. I had the good fortune of seeing Peter's display on Halloween night last year and it was another major inspiration for designing my animatronics controller and ultimately finding Vixen.

Well, have fun with the new motor controller and with Vixen, too. Until next time, Happy Stamping! **NV**

PARTS LIST

Item	Description	Source/Part No.
◗ CPCB	SX28 Proto Board	Parallax/45302
◗ RES	20 MHz Resonator	Parallax/250-02060
◗ R1	4.7K	Mouser/299-4.7K-RC
◗ R2	220	Mouser/299-220-RC
◗ TB1	Two-pos Term	Mouser/571-2828362
◗ TB2	Two-pos Term (x3)	Mouser/571-2828362
◗ U1	L293D	Mouser/511-L293D
	Socket for U1	Mouser/535-16-3518-10
◗ X1-X5	0.1 Pin Header	Mouser/517-6111TG
	Jumpers for X2-X5	Mouser/525-ME-100
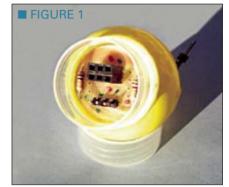
RESOURCES

JON WILLIAMS
jwilliams@efx-tek.com

PARALLAX, INC.
www.parallax.com

VIXEN
www.vixenlights.com

MOUSER ELECTRONICS
www.mouser.com

■ BY L. PAUL VERHAGE

NEAR SPACE APPLICATIONS WITH THE PICAXE — PART 1

■ FIGURE 1

AT ONE BOISE ROBOTICS GROUP (BORG) MEETING last year, Barry Nye, the Technology Guy at Hacker Middle School (Mountain Home, ID) and a founder of the BoRG, told me about a new line of microcontrollers that he had recently discovered. He called them PICAXEs and explained they're preprogrammed Microchip PIC microcontrollers. Like the BASIC Stamps, PICAXEs are programmed with a BASIC interpreter (that's just my speed!) with a syntax that is very similar to the syntax of the BASIC Stamp 1.

Barry recommended the PICAXE-08M — an eight pin microcontroller with five I/O pins (although one pin can only output and one pin can only input) and 256 bytes of memory. What I like about this chip is that three I/O pins are inputs to the chip's built-in analog-to-digital converter (ADC) and that memory not used for program code is available for data storage. Because of its small size

NOTE: I goofed in my last column and forgot to give readers the URL of my website. Data on my previous near space flights (62 to date) is available at **www.nearsys.org**.

and flexibility, some people call the PICAXE-08 (and the 08M) the 555 of the 21st century. You can learn more about this 21st century 555 with Ron Hackett's *Nuts & Volts* mini-series, "Getting Started with PICAXE Microcontrollers," that ran in the January '07 through March '07 issues. (Several sources for PICAXE products are included.) Most readers know that I use a BASIC Stamp for near space applications.

However, I now have two applications where the BASIC Stamp is too large or over-capable for the job. I hesitated to work on these projects because of that, but now that's changed. The PICAXE-08M and -08 are perfect for these two projects I'll talk
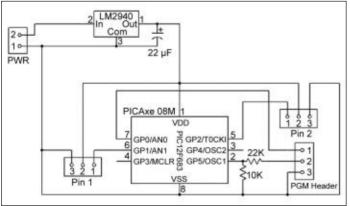
■ FIGURE 2. The PongSat Flight computer can operate two experiments and record data every minute (depending on the size of its flight code) for an entire mission.

about in this and the next column.

IF ONLY MY PONGSAT HAD A BRAIN

Thousands of PongSats have flown since their inception (check my January '07 column for the PongSat application). Most — if not all — have carried passive experiments into near space. I think that's great, but what would make a PongSat more powerful is if it had a flight computer. Because a ping pong ball has a rather tiny volume, its flight computer is going to be rudimentary (unless the flight computer is assembled with surface mount components). As I said, I normally use BASIC Stamps, but even a BASIC Stamp 1 is too large to fit neatly inside a ping pong ball. So Figure 1 shows my solution — a PICAXE-based PongSat Flight Computer (PFC).

My PFC design has two eight bit ADCs for experiments and 200 bytes of data storage (the exact amount of storage depends on the size of the flight code). This means the PFC records data from up to two sensors and stores the results into memory

until recovery. Each ADC input has its own +5V and ground pin, so it's easy to plug sensors to the PFC.

Even though the PICAXE-08M is a small micro, the PFC PCB is divided into three levels in order to fit inside a ping pong ball. Each level has its particular function and is connected to the other levels through a pair of headers and receptacles (called the side receptacles). The headers and receptacles allow all three levels to be stacked and destacked at will; so the levels are not permanently connected together.

The first level (Figure 3) is the interface level and it's exposed when the PongSat is opened. This is the level where sensors are attached, the PFC is programmed, and the mission data is downloaded. The two resistors on this level are the pull down and current limiting resistors used for programming the PICAXE. The programming header is a 1x3 male header and the I/O ports are 2x3 female receptacles. Since the PFC is made with a single sided PCB (printed circuit board), the two side receptacles (which connect the first level to the second level) are lifted above the PCB by 1/10" so a soldering iron can fit beneath and solder them to the PCB. The first level PCB is 3/4" in diameter.

The second level (Figure 4) is the logic level. The PICAXE-08M is mounted on this level between two rows of header pins. The longest pins of the headers are soldered pointing down. This leaves the header pins long enough to connect to the receptacles in the first and third levels. The PCB for the second level is 1/2" in diameter.

The third level (Figure 5) is the power level. There's a low dropout voltage regulator and capacitor soldered to this level. The PFC's power cable passes through a strain relief hole in this PCB before being soldered to the power and ground pads. Currently, my power cable terminates in a two pin header while I experiment with power options for the PFC. The PCB for the third level is 1/2" in diameter.

BUILDING THE PONGSAT FLIGHT COMPUTER

Refer to Figures 6 and 7. Since the

PFC is built with small PCBs, there are a couple of things to be careful with while assembling it.

First Level
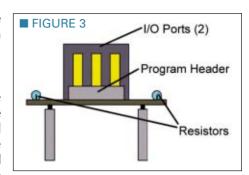
Solder the I/O receptacles and the programming header first. Then flip the PCB over. Unlike the headers and receptacles that were just soldered, the two side receptacles (which are used to connect the PFC levels together) are soldered to the copper side of the PCB (in other words, to the bottom of the PCB). Raise them 1/10" above the PCB to create enough of a gap for the soldering iron to reach the receptacle pins and their PCB pads. Now flip the PCB over and solder the two resistors.
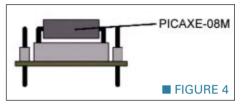
Second Level
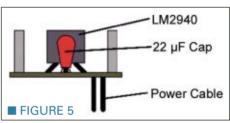
This level is easier to assemble than the first level. Begin by soldering the eight pin DIP socket or PICAXE (if you're comfortable with your soldering ability). The side headers are soldered to the PCB with their longest pins passing through the PCB. If you solder the headers upside down, then the header pins on the bottom will be too short to properly connect to the third level side receptacles.

Third Level

Begin assembling this level by soldering two thin gauge wires to the
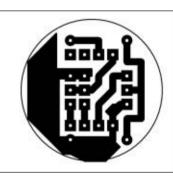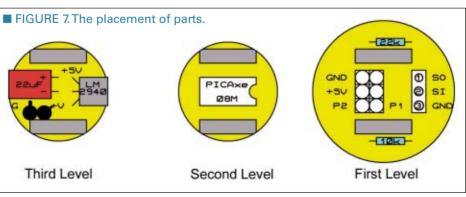
PCB power pads. Then fold the wires over and pass them through the relief holes in the PCB. Since this is the power cable, use a red colored wire for the positive pad and a green or black colored wire for the ground pad. Solder the LM2940 and 22 µF cap in place. Lastly, solder the two side receptacles.

■ FIGURE 3

I/O Ports (2)
Program Header
Resistors

PICAXE-08M

■ FIGURE 4

LM2940
22 µF Cap
Power Cable

■ FIGURE 5

■ FIGURE 6. Mask for copper layer of PCB.

■ FIGURE 7. The placement of parts.

Third Level   Second Level   First Level

■ FIGURE 8. The completed levels of the PFC before stacking.
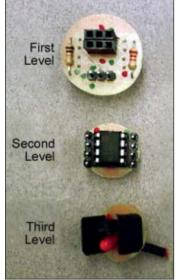
■ FIGURE 9. When stacked, the PFC is 1-1/2" tall and 3/4" across at its widest.

FINISHING THE PFC

Look for bad solders and shorted traces before stacking or applying power to the PFC. To properly fit the PFC into a 1/2" diameter tube, the outside corners of the side receptacles must be trimmed slightly. Use a sharp Exacto knife to carefully scrape away a little of the outside receptacle corners. Next, place a small drop of paint on the front face of each PCB. The paint drops are markers that insure you align the front of each PCB when you stack the PFC. A good paint to use is enamel paint for plastic models. And a good way to apply the paint is with a toothpick. It's also helpful — while you have the paint and toothpicks out — to paint markings next to the ground pin of the programmer

■ FIGURE 10. The downloader connects a 1K resistor between I/O and +5V as illustrated. The downloader is covered in hot glue and heat shrink to protect it from shorting out with sensors that may be plugged in.

header and I/O ports. Use some green model paint and a toothpick for these markings. Now stack the levels together with their orientation dots facing the same directions.

TEMPORARY BATTERY POWER

I'm designing power options for the PFC as I write this article. (I want to develop a power supply that's smaller than a ping pong ball). So for now, use a four "AA" of "AAA" battery holder or a 12 volt "N" size battery and "N" battery holder to power the PFC. The battery cable should be terminated with a two pin receptacle (with recessed pins) to guard against accidental shorts.

DOWNLOADER

A PICAXE overwrites all its memory every time it's programmed. So the PFC's flight code must include the download code. The PFC flight code I've written checks pin 1 when powered up and if it's low, then the PICAXE downloads its stored data. Otherwise, the PFC begins recording sensor values. Figure 10 shows a simple downloader that signals the PFC to begin downloading stored data.

SENSORS

I prefer that the

■ FIGURE 11. From left to right, the download resistor, the temperature sensor, and LED indicator. Each are covered with heat shrink.

PFC sensors be small and plug directly into the ADC ports. So far, I've developed a temperature sensor and LED indicator for the PFC. If you make these, then you'll have enough to fully test the PFC. There will be more sensors covered in upcoming months.

The simplest is the LED indicator, which I built as illustrated in Figure 12. Like the PFC pull-down, the LED indicator is covered in heat shrink and filled with hot glue for protection against shorts.

My first real sensor is a temperature sensor built from a LM335 and 1K ohm resistor. Figure 13 illustrates how it's made. Like the LED and pull-down resistor, it's also covered in heat shrink and filled with hot glue.

FLIGHT CODE

My current program for an LED indicator and temperature sensor is shown in Listing 1. At start-up, if the PFC detects a low on pin 1, it begins downloading the data stored in memory and writing to the terminal program in the PICAXE programmer. But if pin 1 is not pulled low, then the PFC blinks the LED indicator and digitizes the temperature data once per minute. The data is stored in memory until 200 records are recorded. The code stops at 200 measurements because according to the PICAXE programmer, there's 200 bytes left in memory after this program is downloaded. Two hundred bytes is still a lot. That's enough memory for one eight-bit measurement every minute for three hours and 20 minutes (most near space missions don't last that long).

DOWNLOADING PFC DATA AFTER A MISSION

At recovery, make sure the PFC is

powered off so it doesn't record unnecessary data. On a PC or laptop, start the PICAXE Programming Editor. Click on PICAXE in the menu bar and then click on Terminal in the drop-down menu. Make sure a baud rate of 4,800 is selected. Then connect the PFC to the programming cable, making sure the cable is not backwards (the green dot next to the ground pin makes sure of that). Remove any sensor from pin 1 and replace it with the downloader. Then start the PFC by applying power. The data stored in the PFC memory will begin appearing in the Input Buffer window.
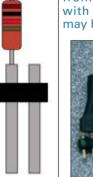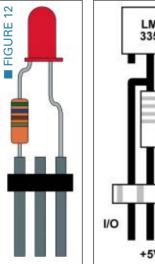
After the last data is displayed, click on Edit in the menu bar and select Copy Input Buffer. Start a text editor like Notepad and click Edit and Paste to copy the data into a document. The results can be edited into a comma delimited file and opened in Excel for final processing.
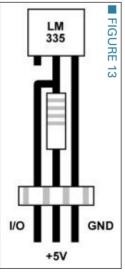
Alternatively, the downloading

LISTING 1

```
PongSat:
  if pin1 = 1 then Get_Data      'pull up resistor on pin 1 means download data

Get_Temp:                        'on a mission
  b2 = b2 + 1                    'increment memory counter
  high 1                         'turn led on
  pause 1000                     'wait one second
  low 1                          'turn off led
  readadc 2,b1                   'digitize lm335 voltage
  write b2,b1                    'write into eeprom
  if b2 = 200 then End_Mission   'if memory is exceeded, end program
  pause 60000                    'wait one minute
  goto Get_Temp                  'get next temperature reading

Get_Data:                        'download data
  b2 = b2 +1                     'increment eeprom counter
  read b2,b1                     'get byte from eeprom
  sertxd (#b1,13,10)             'transmit data via serial port and terminal program
  pause 100                      'wait 1/10 second
  if b2 = 200 then End_Mission   'if end of eeprom, end download
  goto Get_Data                  'get next byte

End_Mission:                     'finished recording or downloading data
  high 1                         'turn led on
  pause 1000                     'wait one second
  low 1                          'turn led off
  end
```

portion of the PFC code can be modified to add a comma to the data as it's debugged (this uses some memory that could be used to store flight data).
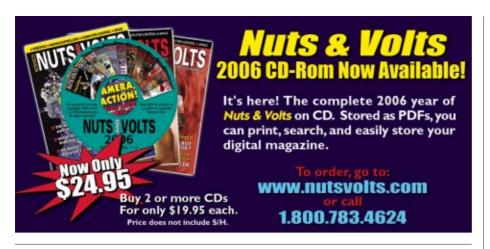
WHAT'S NEXT?

Still to be resolved is the issue of an appropriate PongSat power supply. I have a couple of ideas that I'm working with right now and I expect to share them with you in the next column. I also will develop more sensors. So, I'll experiment with those and let you know how it goes.

I see a lot of potential with the PongSat Flight Computer. The simplicity of the PongSat and its flight computer will make it a fun science project. So you'll be hearing more about PongSats and this flight computer in future columns.

Onwards and Upwards,
Your Near Space Guide **NV**

PARTS LIST

- PICAXE-08M
- LM2940 (+5V, 100 mA, voltage regulator in TO-92 form factor)
- 22 µF tantalum electrolytic capacitor
- 10K resistor
- 22K resistor
- 22 pin receptacle
- 11 pin header

■ FIGURE 12

■ FIGURE 13

LM 335

I/O   GND

+5V

Q&A

■ WITH RUSSELL KINCAID

In this column, I answer questions about all aspects of electronics, including computer hardware, software, circuits, electronic theory, troubleshooting, and anything else of interest to the hobbyist. Feel free to participate with your questions, comments, or suggestions.

Send all questions and comments to:
Q&A@nutsvolts.com

WHAT'S UP:
Join us as we delve into the basics of electronics as applied to every day problems, like:

✔ **Thaw frozen pipes.**

✔ **Turn signal reminder.**

✔ **Audio amps.**

CURRENT SMOOTHING FROM H-BRIDGE

Q In the May '07 issue, there was a question in Q&A about 'cause of current limit.' I'm looking for a design circuit that is similar to this description. I am using a microcontroller to generate 10 kHz PWM and a variable duty cycle to drive an H-bridge amp to control the temperature of a Peltier device. I'd like to add a coil circuit and change to a current form. Could you provide me one? The Peltier device efficiency decreases when the current ripple exceeds 10%.
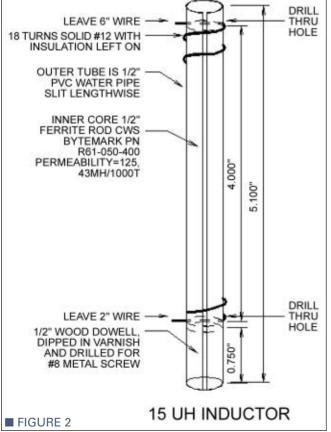
You may wonder why I use an H-bridge. The reason is that the hot/cold surfaces can be exchanged by reversing the current.

— Brian Kuo
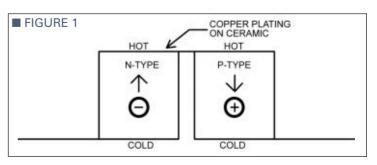
A As Mr. Kuo knows, the underlying theory behind a Peltier device is that when a current passes through a junction of dissimilar metals, one junction gets hot and the other gets cold (the Peltier effect). Don't ask me how it works; somehow the electrons carry away heat on the cold side and transfer it to the hot side. The effect is enhanced by using a semiconducting material for one of the conductors. If the semiconductor is an N-type, electrons carry the thermal energy, but when a P-type is used, holes carry the thermal energy and the hot/cold surfaces are opposite; this makes it easy to series-connect a bunch of junctions (see Figure 1). As you might expect, the resistance of one junction is very low, so hundreds of junctions are connected in series to obtain a drive voltage of 12 volts. Reversing the current reverses the hot/cold junctions allowing the same device to be used for heating or cooling.

As an added bonus, the Peltier effect is reversible (called the Seebeck effect). If you heat the hot side or cool the cold side, the device will produce DC power. A thermocouple is an example of this. A Peltier device used in reverse would be called a thermopile.

Back to the question: In order to smooth out the current pulses using an inductor at 10 kHz and the power being 10 amps at 12 volts, a rather large inductor is needed. The higher the frequency, the smaller the inductor. So, you pay your money and take your choice. I once built a 15 µH inductor for 30 amps

LEAVE 6" WIRE

18 TURNS SOLID #12 WITH INSULATION LEFT ON

DRILL THRU HOLE

OUTER TUBE IS 1/2" PVC WATER PIPE SLIT LENGTHWISE

INNER CORE 1/2" FERRITE ROD CWS BYTEMARK PN R61-050-400 PERMEABILITY=125, 43MH/1000T

4.000"

5.100"

LEAVE 2" WIRE

1/2" WOOD DOWEL, DIPPED IN VARNISH AND DRILLED FOR #8 METAL SCREW

DRILL THRU HOLE

0.750"

15 UH INDUCTOR

■ FIGURE 2

■ FIGURE 1

COPPER PLATING ON CERAMIC

HOT   HOT

N-TYPE   P-TYPE

↑   ↓

⊖   ⊕

COLD   COLD

DC using a half inch diameter ferrite rod, as in Figure 2. I never verified that it worked at 30 amps, but this is the kind of construction that should work. Figure 3 is the current waveform at 500 kHz using a theoretical 15 µH inductor. The same waveform can be had at 10 kHz with an inductance of 800 µH. Since the ripple is low, the best solution is to run at as high a frequency as possible.

Figure 4 is the H-bridge circuit with inductor. The diode is necessary to keep the current flowing when the drive is off. Note that the controller can only PWM one transistor at a time. The left side is either high or low, not PWM. On the right side, PWM the upper transistor for current right to left and PWM the lower transistor for current left to right. The circuit could be made to work with one inductor by adding P and N type MOSFETs to switch the inductor, as in Figure 5.
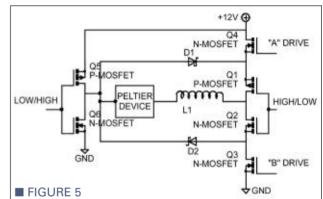
The LM5100 driver is available in three-amp, two-amp, and one-amp drive capability. Any will work but more is better, of course. The LM5100 uses a bootstrap to be able to drive the high side MOSFET. Figure 6 is a simplified schematic. When the H-bridge output goes low, the cap is charged through the diode. When the H-bridge output goes high, the cap supplies charge to the MOSFET gate through the driver. The cap value has to be much larger
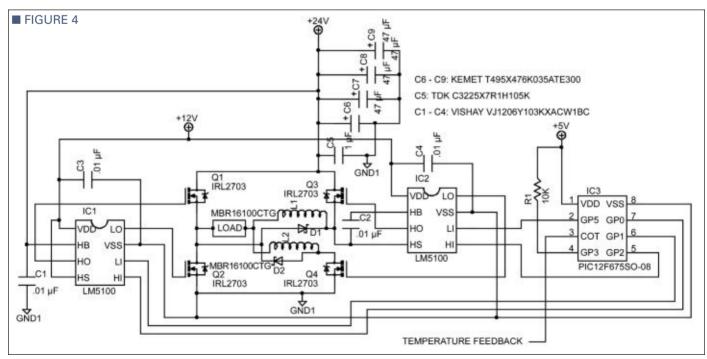
than the input capacitance of the MOSFET. In this case, I made it about 30 times larger.

■ FIGURE 3

CIRCUIT ANALYSIS
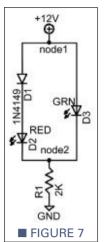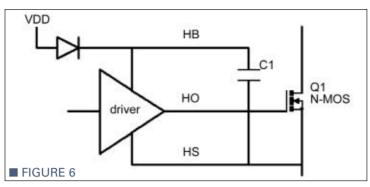
Q Given the circuit shown in Figure 7, how would

■ FIGURE 5

■ FIGURE 4

■ FIGURE 7

■ FIGURE 6
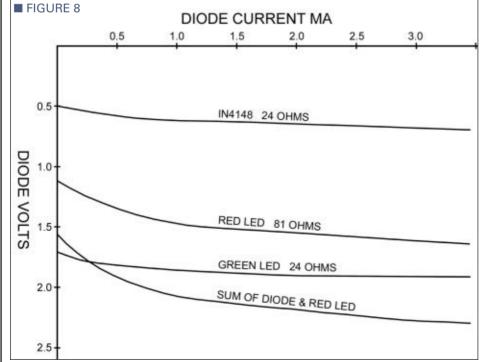
you compute the voltage between node 1 and node 2?
— **Terry Coy**

A When dealing with nonlinear devices such as these, a graphical approach is the easiest. I measured some diodes from my junk box (see Figure 8). Note that the green LED voltage drop is almost constant. It is a better voltage reference than a low voltage zener. Since the 1N4148 and red LED are in series, add the curves voltage-wise. Where the sum curve is higher voltage than the green LED, the green LED will hog most of the current. The series diodes will draw some current; at 1 mA the green LED voltage is 1.85 volts. At that voltage, the series diodes will draw 0.35 mA. Ideally, we should subtract

the 0.35 mA from the green LED curve at 1.85 volts, but the green LED impedance is so low that it will not make a significant difference. Now we need a bigger paper to draw the 2K line and add the green LED to it. Should we now subtract the series diode current from the combined curve? I don't think so because the current through the series diodes also goes through the 2K ohm resistor.

I want to extend the green LED curve to 6 mA. Reading the curve at 3 mA, the voltage is 1.90 volts. Since the resistance is 24 ohms, add 3 mA*24 = 72 mV at 6 mA, making the voltage 1.972 volts at 6 mA. Now add the green LED voltage to the 2K line, as shown in Figure 9. Where this line reaches 12 volts, read the current through the 2K resistor and the voltage across it. I get 10.05 volts, leaving

1.95 volts across the diode array.

INDUCTANCE MEASUREMENT

Q I am trying to measure some small inductors with reasonable accuracy. What I need is an amplifier with a gain of 10 from 10 kHz to 1.59 MHz that will output 10 volts RMS into a 100 ohm load. The 1 VRMS input is from a signal generator with 50 ohm output impedance. Also available is ±20 volts DC from a power supply using LM317 regulators. I realize that I am measuring impedance not reactance, but it is easy to measure DC resistance and then use a QBASIC program to calculate inductance.
— **Frank Mastnock**
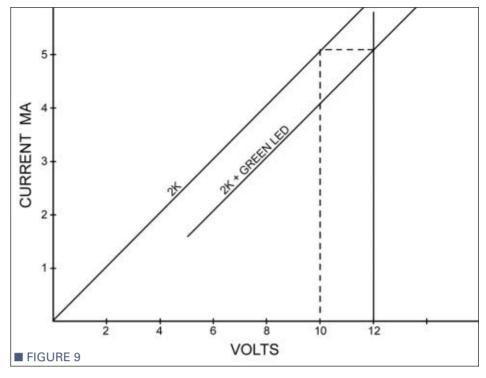
A I am not able to find any amp that will swing 28 volts peak-to-peak at 1.5 MHz. A wide band transformer might work, but there are so many easier ways to do it. Let me count the ways ...

1) Resonate the coil with a known capacitor. If the Q is 10 or more, this is easy (Q = Xi/R). Find the frequency of peak amplitude or frequency of zero phase and calculate $L = 1/(4\pi^2 f^2 C)$. The accuracy of this measurement is 1/2 % for Q greater than 10. For low Q, a different method is needed. I use a series resistor and find the peak frequency on the oscilloscope. That is accurate enough for my purposes.

2) Drive the coil with an AC current source and measure the voltage. In this case, you are measuring the impedance (Z), so measure the resistance and compute $Xi = \sqrt{(Z^2 - R^2)}$ and $L = Xi/(2\pi f)$. The problem here is in finding a variable frequency AC current source.

3) Drive the coil with an AC voltage source and measure the current. The current could be measured using a sense resistor or a current transformer. In either case, two meters will be needed: one to measure the voltage across the coil and another to measure the current. Again, you are measuring Z = E/I and have to measure the

■ FIGURE 8
DIODE CURRENT MA

resistance as above. If you only have 1 VRMS to drive the coil, the current could be quite low in some cases.

4) Use either method 2 or 3 above to drive the coil and measure the phase angle between the source voltage and the current. Find the frequency where the phase angle is 45 degrees. At this point, $Xi = R$. You can measure R to find X. Keep in mind that R includes all the series resistance, including the source resistance of the signal generator.

5) Drive the coil with a ramp (sawtooth) current and measure the voltage. The voltage will be constant as long as the ramp lasts, but you will need a sample-and-hold to get the reading. Also, this is not AC, so there may be an error due to DC saturation of the core.

6) Drive the coil with an AC square wave and measure the current. The current would be a linear ramp for a perfect inductor, but the equivalent series resistance reduces the voltage available across the coil as the current increases, causing the ramp to flatten out in an exponential curve. The time for the curve to reach 66.7% of its final value is known as the time constant and, in that case, $T = L/R$. Measure R and T to find L.

A circuit for measuring phase is shown in Figure 10. You can use this circuit for methods 1 and 4. In method 1, you are looking for the frequency where the phase between the source and the current is zero; in method 4, you are looking for the frequency where

■ FIGURE 9

the phase between the source and the current is 45 degrees. Maximum output is at 180 degrees phase; you could swap B inputs, with a resistor in place of the inductor, to get that number; 45 degrees will be 1/4 of Vmax.
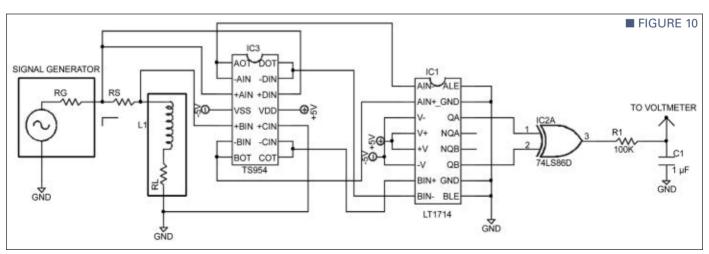
In Figure 10, Rs is the current sense resistor. If you are resonating the coil, Rs can be large and you don't need to know what Rl is; but if the Q is low, then Rs should be small because $R = Rg+Rs+Rl$ and the generator may not go to a high enough frequency to make $Xl = R$.

IC3 is a quad op-amp buffer. I put that in because I was afraid that the high speed comparator, LT1714, would load the circuit. The LT1714 is
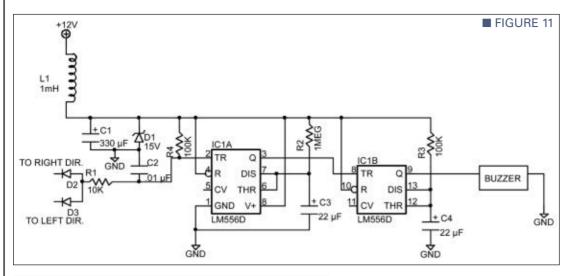
a dual comparator that outputs square waves representing the source voltage and current. IC2 is an XOR phase detector, which its output is filtered to DC so it can be measured on a meter.

TEMPERATURE MONITOR QUESTION

Q I am looking for a temperature monitor circuit that will monitor temperature over a range of 0 to 350°F. I am considering using thermocouples rather than thermistors because of the range, as well as the small size. I want to monitor one or two input temperatures

■ FIGURE 10

TURN SIGNAL REMINDER PARTS LIST

Part	Description	Part Number
L1	1 mH, 200 mA	580-17105C
C1	330 µF, 16V	647-UHE1C331MPD
D1	15V Zener, DO-41	78-1N4744A
D2, D3	1N4148	78-1N4148
C2	0.01 µF, 50V	581-SR215C103KAR
R1	10K, 1/4W, 5%	291-10K-RC
R2	1M, 1/4W, 5%	291-1M-RC
R3	100K, 1/4W, 5%	291-100K-RC
C3, C4	22 µF, 50V, 10%	74-199D50V22
IC1	LM556N, DUAL TIMER	511-NE556
BUZZER		847-FPWB-12

with an LCD or LED display. I do not need control functions. I have been looking at the AD 594/AD 595 IC that will compensate the inputs. I am confused on how to convert to a digital output for a display. I have also been looking at a PIC that will convert directly for a display. Do you have any suggestions for a circuit that is relatively simple that does not require lots of components?

— **Daniel Gioia**

AThe really simple solution is to use a Fluke model 80TK thermocouple module which plugs into a digital voltmeter to read the temperature directly, in degrees F or degrees C. The Fluke module is available from Mouser (**www.mouser.com**), part number 676-80TK. It will plug into the Mastech model MAS838 meter, available from Jameco (**www.jameco.com**), part number 220741.

You might also want to consider an LM35 temperature IC. Its output is 10 mV per degree C which could be read on a digital meter.

TURN SIGNAL REMINDER

QSeveral years ago in a different publication, there was a time delay circuit for developing a reminder signal for automobile turn signals after a short time (maybe 30 seconds or so) to remind the driver to cancel turn signals. The circuit used a 555 then. Did you see it, or do you have a circuit to complete it?

— **Bob Haskett**

AYou can buy an extra loud turn signal switch at most auto parts stores. The switch is a bi-metallic device that plugs into something under the dash, sometimes on the fuse panel. If that is not loud enough, the buzzer that you requested may be the answer.

The output of the 555 goes high as soon as it is triggered, stays high for the timed period, then goes low. That is not what you want. You want the output to stay low for a timed period then go high for a shorter time, driving a buzzer. That takes two 555s, also known as a 556 dual timer. In Figure 11, the trigger input (D2 and D3) is connected to the turn signal wire. The parts, L1, C1, D1, R1, C2 are all for protection against transients. Power is obtained from a wire that is live when the key is on; the radio wire is a good place. All the part

numbers shown in the Parts list are available from Mouser (**www. mouser.com**).

AUDIO AMP

QI have a KIA6221AH 30W BTL dual audio power amp chip. I was thinking of using it to hook directly to my TV dish audio output for music. Do you have suggestions on a schematic or better choice of amp? I can find the data sheet, but it is a test circuit and needs a volume control.

— **Terry T.**
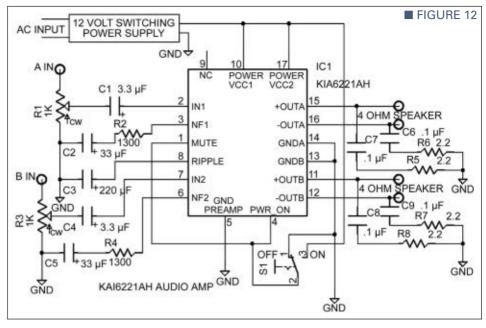
AThe gain of the KIA6221AH is internally set, but you can vary it with an external resistor. The stability is a function of gain, so it is not advisable to use this as a volume control. The schematic given is pretty much the recommended one and there is not enough data given to vary from that by much. The most you can expect to get out is 10 watts per channel at low distortion. With four ohm speakers, the RMS voltage output (assuming the data sheet uses RMS power and not some meaningless "music equivalent") is $E = \sqrt{(40)} = 6.3$ VRMS. The peak voltage for a sine wave is 8.9 volts, but music is not sinusoidal; even so, a 12 volt supply looks okay. The filter caps for a transformer-rectifier power supply will be humungous, so I recommend a switching supply. Mouser part number 680-MSM6012 will be very reliable at $61.19, or 552-PSA-60-112-R at $34.93 is more economical.

The signal from your TV dish output should be line level (about one volt) so you don't need a lot of gain. A gain of 10 (20 dB) should be sufficient, but to be sure, I set the gain at 30 dB (X32). Using the formula on the data sheet, Rf = 1,300 ohms. Rf is R2 and R4 on the schematic in Figure 12. I used the same cap values as used for 40 dB gain on the data sheet; I don't think it will have any effect other than bring the low frequency response down to lower frequencies.

Since there are not a lot of parts, you could mount them on perf board, being careful to keep the A and B power grounds separate from the preamp and input grounds. Connect the grounds together as close to the power supply as possible. You will need a heatsink for the IC because a linear amp is 50% efficient, at best. If the amplifier is capable of 20 watts output, it must be able to dissipate 20 watts also. Crydom model HS-1 looks good; it has tabs so you can mount it vertically and bolt the IC to it. I want to keep the temperature rise down to 60 degrees C at 20 watts. That means the thermal resistance should be 60/20 = 3 degrees C per watt. The HS-1 is 2.5 degC/W so it will work without a fan. The heatsink is for a solid-state relay. You will need to drill and tap holes to mount the IC. The HS-1 is available from Allied Electronics (**www.alliedelec.com**), part number 682-0063; cost $7.89.

■ FIGURE 12

NIMH BATTERY CHARGING

Q While playing on the *N&V* Bulletin Board, I came across **www.batteryuniversity.com**. I have wanted to charge NiMH batteries using solar power, but after reading at Battery University, I came out more confused than informed. I bought six large solar panels from Goldmine Electronics (Cat #G16129; output is 15 to 17 VDC open circuit voltage and short circuit current is 0.11to 0.14 amps) with this goal of charging 10 D size batteries for a total of 12V. From what I see from Battery U, this is a great project for a PIC or a BASIC Stamp. I just wish there was something out there to give an idea how to wade though all the important stuff on how to do this. Could you please do an article on how to do this?
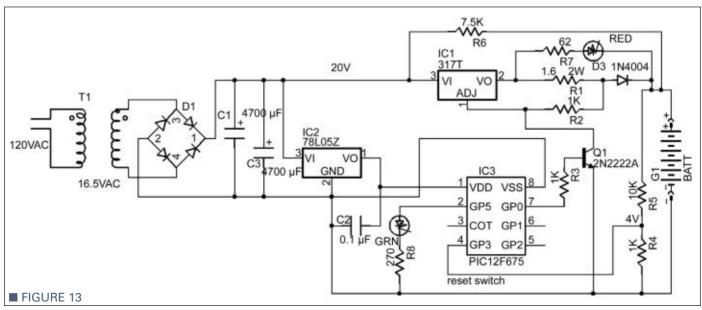
I don't want to have to build into a project something I am going to have to drain every month. What happens if I need my batteries after a computer automatically drains them? Again, maybe you could better explain the ins and outs of Ni-MH and NiCad, and how to exercise them.

— **David W**

A The memory effect in NiCad is a popular myth that happened because many chargers overcharge and damage the batteries, reducing the capacity unless the battery is first fully discharged. The charger that I will describe here will not overcharge regardless of the initial state of charge, NiCad or NiMH. Batteries are rated in ampere-hours at a given current (called C). The recommended charge rate is

■ FIGURE 13

```
REM  DEVICE = 12F675
REM USE INTERNAL OSCILLATOR, OUTPUT IS ON GP4 (PIN3)
REM CONFIGURATION: INTOSC CLOCKOUT, WDT DISABLED, PWR UP ENABLED,
    'MCLR = INPUT PIN,BROWN OUT DISABLED, NO PROTECTION
REM  CLOCK OUT ON PIN 3   (GP4)
REM CHARGER SWITCH ON PIN 7 (GP0)
REM A/D INPUT ON PIN 4 (GP3)
REM GREEN LED ON PIN 2 (GP5)
ADCON0 = %00001101        'LEFT JUSTIFIED, VDD REF, CHANNEL 3, A/D
                          ' INITIALLY OFF
ANSEL = %01001000         'CLOCK IS FOSC/4, INPUT TO GP3
TRISIO = 0                'ALL OUTPUTS EXCEPT GP3
GPIO = 0                  'ALL OUTPUTS INITIALLY LOW
DEFINE OSCCAL_1K 1        'SAVES OSCILLATOR CALIBRATION
DEFINE ADC_BITS 10
DEFINE ADC_CLOCK  5       'INTOSC_CLOCKOUT?
DEFINE ADC_SAMPLEUS 50    '50 MICROSECONDS SAMPLE TIME
VOLT VAR WORD
OLDVOLT VAR WORD
GREEN VAR GPIO.5
SWITCH VAR GPIO.0
   START:
LOW SWITCH                'TURNS ON CHARGER
PAUSE 60000               'DELAY 1 MINUTE
HIGH SWITCH               'TURN OFF CHARGER
ADCIN 3,VOLT              'SAMPLE CHANNEL 3, STORE BATTERY VOLTAGE
IF VOLT < OLDVOLT  THEN
      GOTO STOPCHG
ENDIF
OLDVOLT = VOLT
GOTO START
    STOPCHG:
    HIGH GREEN
    STOP
    END
```

■ FIGURE 14

C/10. The charge time for a dead battery is 15 hours because you have to put in more ampere-hours than you get out. Even this rate is too high to leave the battery connected beyond the 15 hours.

Two methods are used to detect the full charge condition: temperature rise and battery voltage. Some batteries have a thermistor installed so the controller can detect the temperature rise and shut down the charger. That is not the approach used here. When the battery is being overcharged, gas recombination occurs which raises the temperature and reduces the output voltage. This charger stops the charging momentarily and checks the battery voltage. If the voltage is not higher than the last check, the charging is stopped.

Your D size cells are rated 2.5 AH which means it will supply one-half amp for five hours with a final cell voltage of one volt. The C rate for this cell is 2.5 amps; so the charge rate should be 250 mA for 15 hours. The circuit in Figure 13 will charge 10 cells in series at 750 mA. Full charge should be achieved in five hours. The red LED lights to show that charging is in process; the green LED lights when the charging stops. The circuit will charge any number of cells less than 10. You just have to change the voltage divider to provide between one and four volts at the A/D input. The charging current is set by R1: R1 = 1.2/Ichg. The program, written in PICBASIC, is in Figure 14.

SIMULATION SOFTWARE

Q I have been looking everywhere for electronic simulation software for the PC, but most of the software out there is for educational institutions and it costs an arm and a leg for the software and licensing fees. I want design software which allows a simulation to view the result of the circuit, i.e., an LED turning on or off. It must have testing tools such as an oscilloscope or multimeter. Could you recommend a software similar to SPICE but is within a reasonable price range for an electronics student?

— Anonymous

A A Google search for "free schematic capture spice" will turn up many possibilities, but most of them are limited in circuit size or output in order to entice you to buy the full-up version. The only free, full feature simulator that I am aware of is LT spice/SwitcherCad III from Linear Technology. The down side is that the library has only Linear parts in it, but you can import other models or make your own. Go to **www.linear .com** and download the program for free. If you have trouble using LT spice, the folks at the *Nuts & Volts* online forum will help you out. Spice originated at UC Berkley and at one time was free. Probably still is.

THAW FROZEN PIPES

Q Is it possible for an electronics hobbyist and long-time *Nuts & Volts* reader to construct a frozen water pipe thawing power supply?

Do you have a schematic? The output is four to six volts AC (RMS? I don't know) at 300 amps.

Plumbers want $600 to come out if you can find one. We found a guy for $200 and 20 minutes later, the water was running. Now they are frozen again. You can buy thawing machines new for $700.

— Terry Romanov

A All you need is a transformer. I assume we are talking about thawing 1/2 inch copper pipe. I guess that 1/2 inch copper is similar to #000 wire which has a resistance of 0.6 milliohms in 10 feet; 100 watts should melt the ice in short order, so calculating the current: I = sqrt(100/.0006) = 408 amps. You probably won't use #000 wire to hook up the transformer; something like #4 welding cable would work. Ten feet of #4 has a resistance of 2.5 milliohms which will drop one volt at 400 amps. If you rewind a transformer for two volts output, that is a ratio of 120/2 = 60:1 and the secondary can put out 900 amps before the primary will trip a 15 amp circuit breaker. You only need 400 amps, so an 800 VA transformer will be big enough.

I looked on eBay and found a 750 VA transformer, input: 120/240 VAC, output: 12/24 VAC; starting price is $20. You will need to remove the secondary windings and replace them with the #4 welding cable. Count the number of turns removed so you know the turns per volt, then rewind with two volts worth of turns. Put some automotive jumper cable clamps on the secondary wires and you are in business. If you are lucky, the primary will be the first winding and you won't have to disturb it. If you have to rewind both windings, it may be possible to take the iron core apart to make it easier, but if you don't have to, it is better to leave the core alone because it may buzz after you put it back together (not a problem, just annoying).

If the welding cable is too thick to put in the transformer, you can cut the old secondary winding wire into six or eight equal length pieces and connect these all in parallel after winding into the transformer. You can get a splicing clamp to connect to the #4 welding cable, but keep the secondary wires as short as practical; you can use heavy duty extension cord on the primary.

CAPACITOR QUESTION

Q What is the best way to figure the correct size of electrolytic capacitors to use on a DC power supply? I have seen commercial power supplies with both single and multiple sets of capacitors and always wondered why the difference and what were the benefits of both designs?

When multiple capacitors are used, should they be of different sizes? If this topic has already been addressed in a previous Issue, please let me know where to look.
— **Bill Blackburn**

A I am sure the subject has been covered before, but it does not hurt to repeat it. Filter caps perform two important functions: smoothing the input pulses from the rectifiers and absorbing pulses from the load. Aluminum electrolytic capacitors are good at 120 Hz but not so good at 100 MHz. Ceramic or film capacitors work

best at high frequency, so two types should be used in the power supply. Short leads are important at high frequency, the film or ceramic caps should be right at the power supply output terminals. The size of the smoothing cap depends on the output current. A rule of thumb is 80,000 µF per amp for 100 mV ripple. Or, use this equation:

$$C = I*dT/dE$$

where C is the capacitance in farads
 I is the current in amps
 dT is the time between pulses in seconds
 dE is the peak ripple voltage in volts

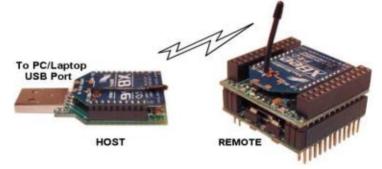This equation will also tell you how large a bypass cap is needed for high frequency.

All capacitors have an equivalent series resistance (ESR). Film and ceramic caps have such a low ESR that it is generally not specified on the datasheet, but electrolytic caps have significant ESR that can cause overheating due to ripple current. For this reason, multiple caps are used in parallel.

Another factor for using parallel caps is that ripple current times ESR creates a ripple voltage that can only be reduced by using a cap with lower ESR or parallel caps. It turns out that it is more economical to use multiple parallel caps rather than one low ESR cap of the same total value. When using parallel caps, they should all be the same. Otherwise, the current will not divide equally between them.

Another factor that TJ Byers had covered is that a capacitor will become series-resonant with its lead wires at some frequency. The cap impedance is a minimum at resonance but is inductive above resonance, so the impedance increases with frequency. The datasheet will give you an idea where the resonance will occur, but since it is entirely dependent on lead length and layout, choosing the cap becomes an art. **NV**

NEW
P R O D U C T S

■ HARDWARE
■ SOFTWARE
■ GADGETS
■ TOOLS

ADJUSTABLE
DC-DC CONVERTERS

AnyVolt Micro is the latest in Dimension Engineering's line of adjustable DC-DC converters. AnyVolt Micro is the successor to the popular AnyVolt Mini, adding thermal and overcurrent protection while simultaneously reducing size and weight.

AnyVolt Micro can take an input between 2.6V and 14V and convert it into another voltage between 2.6V and 14V. You choose the output voltage you want by adjusting the onboard potentiometer with a screwdriver.

The AnyVolt series of DC-DC converters is unique in that it allows you to step voltage up or down — effectively eliminating the problem of a drop-out voltage. For example, if you have a project you are powering with four Alkaline AA batteries and you need a regulated 5V source, AnyVolt Micro can operate across the battery pack's 4V-6V operating lifespan and give a constant 5V output. It is also a great choice for stepping up voltage from two AA batteries.

Currents of up to 0.5A can be drawn from the device — the exact limit will depend on your input/output voltage needs. The product's datasheet has a handy reference table showing the current limits at various input and output voltages.

AnyVolt Micro retails for $19.99 and is available from the Dimension Engineering website.

For more information, contact:
Dimension Engineering
Web: **www.dimension engineering.com**

uM-FPU V3.1
FLOATING POINT COPROCESSOR

Micromega Corporation announces the release of the uM-FPU V3.1

Floating Point Coprocessor chip. The new chip extends the powerful feature set of the original uM-FPU V3 chip to include serial I/O support, NMEA sentence parsing, block transfers, additional matrix operations and string support, and many other enhancements.

The new serial I/O capabilities with NMEA sentence parsing make it easy to add GPS data to embedded system designs. GPS data can be read and processed directly by the uM-FPU V3.1 chip, saving I/O pins, memory space, and execution time on the microcontroller, which can then be used for the main application. As an added benefit, GPS data is immediately available on the uM-FPU V3.1 chip for further navigational calculations using the powerful floating point instruction set.

The uM-FPU V3.1 chip interfaces to virtually any microcontroller using an SPI interface or I^{2}C interface, making it ideal for microcontroller applications requiring floating point math, including GPS, sensor readings, robotic control, data transformations, and other embedded control applications.

The uM-FPU V3.1 chip supports 32-bit IEEE 754 compatible floating point and 32-bit integer operations. Advanced instructions are provided for fast data transfer, matrix operations, multiply and accumulate, FFT calculations, serial I/O, NMEA sentence parsing, and string handling. The chip also provides two 12-bit A/D channels,

two digital outputs, an external event counter, Flash and EEPROM storage, and serial I/O up to 115,200 baud.

The uM-FPU V3 IDE (Integrated Development Environment) makes it easy to create, debug, and test floating point code. The IDE code generator takes traditional math expressions and automatically produces uM-FPU V3.1 code targeted for any one of the many microcontrollers and compilers supported. The IDE also supports code debugging and programming user-defined functions. User-defined functions can be stored in Flash using the IDE, or stored in EEPROM at run-time. Nested calls and conditional execution are supported. User-defined functions can provide significant speed improvements and reduce code space on the microcontroller.

The uM-FPU V3.1 chip is RoHS compliant and operates from a 2.7V,

3.3V, or 5V supply with power saving modes available. SPI interface speeds up to 15 MHz and I^{2}C interface speeds up to 400 kHz are supported. The chip is available in an 18-pin DIP, SOIC-18, or QFN-44 package. The single unit price is $19.95 with volume discounts available.

For more information, contact:
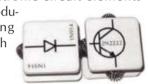**Micromega Corporation**
1664 St. Lawrence Ave.
Kingston, ON K7L 4V1
CANADA
Web: **www.micromegacorp.com**

SPRING
CIRCUITS

RMD3 announces the launch of the SpringCircuits product line — a set of electronic circuit elements placed in modular insulating housings with bent-spring connectors.

The circuit element housing is called a SpringCircuits "piece." The bent-spring connectors make for fast connect and disconnect with other pieces. The laminated graphic label on each piece depicts which circuit element is within the housing and allows for dry-erase marker notations on the circuit. A hook fastener at the bottom of each piece allows for placement on a loop-fabric board (also available from RMD3) and portability of circuits built with SpringCircuits.

RMD3 also offers a traditional breadboard compatible with Spring Circuits which is mountable on the loop-fabric board with the Spring Circuits pieces. More circuit elements are available on the website.

SpringCircuits is suitable for hobbyists, enthusiasts, educators, and even professionals who need to throw together a circuit on-the-fly or make a presentation.

The SpringCircuits Starter Kit includes 31 pieces, six jumper wires, a loop-fabric board, a battery pack, and dry-erase marker and costs $125 plus shipping and handling.

Orders are taken at the RMD3 website.

DIGITAL
COMPASS

A new, low-cost, three-axis, tilt-compensated, solid-state digital compass that provides "drop-in compatibility" with most popular digital compasses has been introduced by OceanServer Technology, Inc.
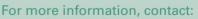
The OS3000 Digital Compass is a three-axis, 1.4" x 1.8" PCB and includes RS-232 and USB connectivity, and a 24-bit A/D converter with digital filters for easy integration into a wide range of applications. Accurate to 1° azimuth, with 0.1° resolution, tilt-compensation up to ±60°, and 0.1° resolution for roll and pitch, the compass components have a 50,000 G shock rating.

Providing a programmable update rate from 0.1 to 20 Hz, an ASCII interface, and hard-iron calibration, the OS3000 Digital Compass can be easily embedded into another device and provides precise heading and roll and pitch data, and is ideal for rapid attitude measurement. It incorporates a three-axis Honeywell Magneto resistive sensor, a MEMS accelerator, and is RoHS compliant.

The OS3000 Digital Compass sells for $249 each or $199 each for 10, with larger quantity discounts offered.

■ LEVEL RATING SYSTEM

To find out the level of difficulty for each of these projects, turn to our ratings for the answers.

●●●● . . . . Beginner Level

●●●● . . . . Intermediate Level

●●●● . . . . Advanced Level

●●●● . . . . Professional Level

I planned on building a wireless station this month but, due to several requests,

I decided to show you how to build a couple of different standalone barometric pressure systems.

First, we will build a graphical plotting display that will keep track of nearly 20 days of hourly readings and give you a 12 hour weather prediction. The second system will actually speak the current pressure and inside temperature when you push a button.

DOUBLE FEATURE: TWO BAROMETRIC PRESSURE SYSTEMS IN ONE
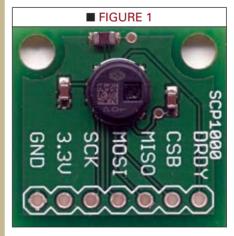
The heart of both systems is the SCP1000 pressure sensor. The SCP1000 is an absolute pressure sensor that requires no calibration and will give up to nine readings a second. The sensor is the most accurate and stable pressure sensor I have ever used. The resolution is so fine that it can register a change in pressure when the sensor has been raised a foot or so off the table.
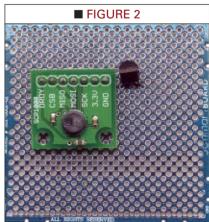
Normally, the SCP1000 would be difficult for the hobbyist to work with due to its small size and form factor, but a company called Sparkfun Electronics has provided a special breakout board shown in Figure 1. It has the sensor installed and a 0.1″ header pad. The SCP1000 sensor itself comes in both SPI and I^2C versions, but I found the SPI the easiest to interface. This is the sensor used on the Sparkfun breakout board.
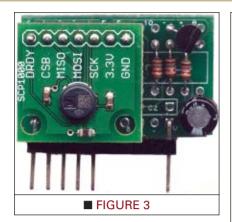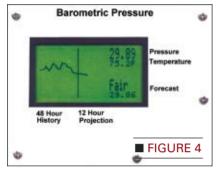
The SCP1000 is a 3V device and needs a voltage of 2.4 to 3.3 volts to operate. This also means the interface leads cannot exceed the supply voltage. We will be using a 5V system so we will need to create a 5V interface for the sensor shown in Schematic 1.

To wire this interface, you have a couple of options. First, you can use some sort of protoboard like the Schmartboard shown in Figure 2. To make things even easier, Kronos Robotics (my company) has a 3.3V to 5V interface kit. The kit has an application note that gives you step-by-step instructions on how to build the small interface board shown in Figure 3.

■ FIGURE 1

■ FIGURE 2

■ FIGURE 3

Barometric Pressure

Pressure
Temperature

Forecast

48 Hour History   12 Hour Projection

■ FIGURE 4

■ SCHEMATIC 1

To use the board, you attach one of the included headers to the SCP1000 breakout board and plug it into the interface board. You will find an application note at **www.kronosrobotics.com/Projects/SCP1000.shtml**.

Barometric Pressure Plotter

To plot and display the barometric pressure, we will be using another Sparkfun product — a graphic LCD display for under $20. This is a 128 x 64 (B&W) display with backlight (shown in Figure 5). Note that I added the 20-pin header.

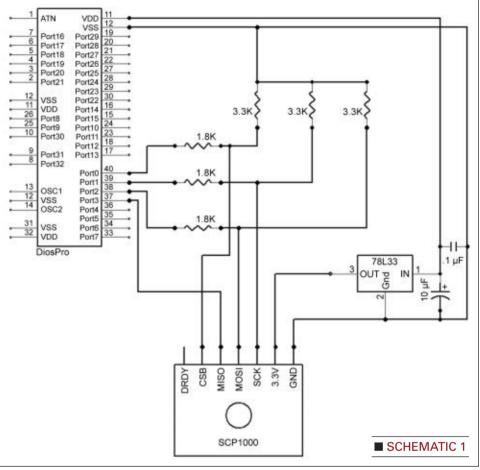The LCD uses a parallel interface and is connected to the DiosPro microcontroller as shown in Schematic 2. While this may seem a bit complicated, to make things real simple, Kronos Robotics has a carrier board called the "Dios Universal LCD Carrier" shown in Figure 6. We will be using this carrier with a

DiosPro to collect and store data from the SCP1000 sensor. This data will be analyzed and then plotted on the graphic LCD.

Plotter Construction
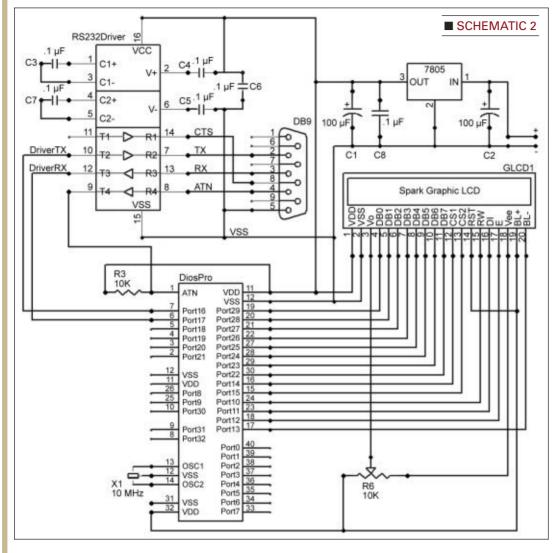
If you use the Universal Carrier and the SCP1000 interface shown, then the display assembly is quite simple to build.

· **STEP 1:** Assemble the Dios Universal LCD carrier. Place the I/O, Keypad, UART, and SW headers on the top of the board and bend them slightly so they will not interfere with the LCD when installed.

· **STEP 2:** Assemble the interface board for the SCP1000 using the application note found here: **www. kronosrobotics.com/Projects/SCP10**

■ FIGURE 5

■ FIGURE 6

■ SCHEMATIC 2

cut a hole for the display since it's transparent.

Keep in mind that the dimensions are given just as a guide. You may want to use a different size if your layout is different.

- **STEP 4:** Attach the Universal LCD Carrier to the lower base as shown in Figure 7. Make sure you leave some room for standoffs.

- **STEP 5:** Attach the SCP1000 and interface to the base as shown using some double-stick foam tape.

- **STEP 6:** Mark and drill holes for the five 1" standoffs shown. Before installing the standoffs, place the base over the top piece and mark the holes so you can duplicate them for the standoffs.

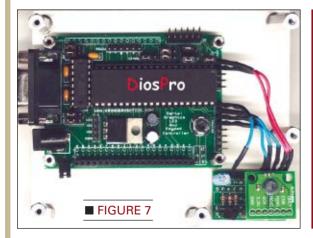- **STEP 7:** Using five jumpers, connect the sensor interface to the Universal LCD Carrier. I prefer using the Schmartboard jumpers. In this case, I used the blue 2" and red 3" jumpers.

- **STEP 8:** Attach the LCD to the Universal Carrier then attach the top cover to the standoffs. If you are not using transparent material, you will have to add a cutout for the display. To mark this, I attached the cover, then with a fine point marker, I noted the position of the display on the underside of the board.

Testing the Display

To program the DiosPro, you need to install the free compiler and connect the Universal Carrier to your PC with a nine-pin serial cable and plug a DC

00.shtml.

Then install the seven-pin header on the top of the board and bend the pins as shown in Figure 7.

- **STEP 3:** Cut two pieces of compressed PVC to 4.5" x 3.5" to be used as the base and top. You can use acrylic or just about any material. Acrylic can be purchased at most home centers. The nice thing about using acrylic is that you don't need to

■ FIGURE 7

Program 1

```
'SCP1000-D01 Test
func main()
   dim pressure as float
   SCPinitD01(0,1,2,3)
   SCPsetmodeHR()

loop:
   pressure = SCPreadpressure()
   print {7.0} pressure
   goto loop

endfunc

include \lib\SCP1000.lib
```

power source into the 2.1 coax. Refer to the carrier instruction manual for more details.

To test the interface to the SCP1000, load and run Program 1. This will display the pressure reading in Pascal units on debug terminal.

I have also included a second program called Program2.txt that will display the temperature.

The program called bargraph1.txt is the main plotting program. While the program is a bit lengthy to present here, I will describe a few of the details that you may want to change in the program.
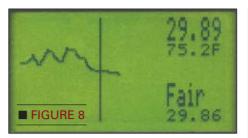
Station Pressure

At the very beginning of the program is a statement where I assign a constant called offset. This is a value that will allow you to change the absolute pressure value to the station pressure. This value is added to the absolute value. You should change this value so that your pressure gauge reads the same as your local forecast.

Default EEPROM

The first portion of the plot is the last 48 hour history. This data is saved into the first 96 EEPROM locations. When you program the DiosPro, the data statements at the beginning of the program initialize these locations. You can comment these statements out if you want to experiment with your exiting data so that they won't get cleared.

Data Dump

Once you have programmed the DiosPro and have verified that it is working properly, you can configure the program port to connect to the onboard hardware UART by setting the DB9 jumpers. The small bit of code following the loop label tests for a character value of 65 at each pass. If this value is received, the complete 20 day history will be sent out the UART at 9600 baud. The data is dumped with the low order byte first, then the high order byte. Each byte pair represents one hour of data with a total of 460 hours. The first pair is

■ FIGURE 8

the current hour index at the time of the dump.

The Display

The display has a vertical line near the center of the display shown in Figure 8. The plot to the left of this line represents the last 50 hours of pressure readings. The plot to the right of this line is a 12 hour projection. On the upper righthand side of the display is the current barometric pressure and inside temperature. On the lower righthand side is the 12 hour forecast and pressure.

How Well Does it Work?

I have been using this pressure sensor for the last couple months and it works pretty well. It has accurately predicted the weather for most changes in my area. For instance, while I was writing the display indicated that a change in the weather was going to occur in the next 12 hours. My grass was getting tall and if it were to rain I would have to wait another week to cut it, so I stopped everything and took out my mower. Sure enough, about 13 hours later it started to rain.

I prefer the SCP1000 pressure sensor over the 1-Wire sensors that I have used, as it seems to give a more reliable reading and does not require 14V to operate.

Going Further

All that is needed to make this display wireless is to add a Zigbee unit. I will look into doing just that when I build the wireless station next month.

I had experimented with the SCP1000 for use in other projects like

■ FIGURE 9

my R/C helicopter and found that in order to get the high resolution required, you need to read the SCP1000 about once every 1.8 seconds. This is too long for this type of application, however, I have read where others have taken two SCP1000s and alternated the readings in order to double the sample rate. This also gives you some redundancy in case of a failure.

Talking Barometric Pressure

Now it's time to take a totally different approach and build a talking barometer. I wanted to keep things as simple as possible, so we will take the modular approach on this project. I will take various boards that are readily available, both assembled and in kit form, and create the talking barometer shown in Figure 9.
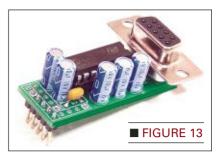
Pressure Talker Construction

If you can solder, then you can build this project. Even if you can't, you can probably get someone to assemble the various modules. Let's
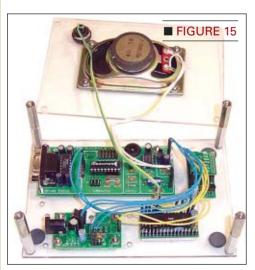

■ FIGURE 10

■ FIGURE 11

■ FIGURE 12

■ FIGURE 13

take a look at each one in detail so you can get an idea on how the project is put together.

Sound Module

I will use the Soundgin sound chip from Savage Innovations to create speech. The Soundgin chip is capable of creating music, sound effects, and a set of phonetic variations called Allophones. The chip itself requires a filter and amplifier so you need a development board. Savage Innovations makes such a board and it includes everything you need to create speech and other sound effects. You will need to add a two-pin header to the pads shown in Figure 10. Unfortunately, the pads are all filled with solder so you will have to remove it in order to install the header. Refer to the small inset as it shows pin placement on the board.

Regulator Module

The module shown in Figure 11 is a simple and inexpensive 5V regulator that can be purchased in kit form, or assembled from Kronos Robotics. The

board also has a header to give you access to the Vin power directly from the coax. We need this to power the sound module. The voltage regulator requires the use of an AC adapter with an output of 6.5 to 14 VDC. This is applied to the 2.1 coax connector, center positive. You can purchase one of these from RadioShack. I have also provided a Jameco part number in the Parts List.

When you assemble this board, you have the option to install the two-pin headers on the bottom for use with a breadboard. For our application, install them on the top of the board so that we can use wire jumpers to connect to the other modules.

Dios Carrier 1 Module

The Dios Carrier 1 module shown in Figure 12 is a small carrier that accepts the DiosPro 28-pin chip. It is also available in both kit and assembled form from Kronos Robotics.

As mentioned, the 12-pin headers need to be installed on the top of the board as shown in Figure 12 so that we can use wire jumpers. This board does not include the PC interface needed to program the chip like the Universal LCD carrier does, so we need to use an EZRS232 module.

EZRS232 Module

In order to program a DiosPro used in a Carrier 1, you need an EZRS232 module. Again, this is a very inexpensive module available from Kronos Robotics in both kit and assembled form (Figure 13).

To plug the EZRS232 driver directly into the Carrier 1 board, you need to create a small five-pin female-to-female header. This can be done by soldering two five-pin headers together as shown in Figure 14. You can also use five jumper wires to connect the EZRS232 driver to the carrier. The EZRS232 driver gets its power from the carrier board.

SCP1000 Interface Module

I have already gone over the SCP1000 interface module available from Kronos Robotics (shown in Figure 3). This module will allow you to plug the Sparkfun SCP1000 directly into our 5V system.

Project Assembly

All the modules are connected together using Schmartboard jumpers shown in Figure 15. The complete diagram is shown in Schematic 3.

· **STEP 1:** Let's start assembly by cutting the base and top pieces. I used acrylic here so others could see the inside of the project, but any material can be used. I used 4" x 8" pieces, but they could be larger if you need the space.

Once cut, place 5/32" holes into each corner of the base and top for the standoffs.

· **STEP 2:** Place your speaker in the center of the top piece and mark the mounting holes. Trace the speaker, as

■ FIGURE 15

■ FIGURE 14

well, to give us an outline so you can drill a series of holes for the sound.

· **STEP 3:** Drill the sound holes as shown back in Figure 9. You also need to drill the hole for the button. For the Jameco button listed in the Parts List, you'll need a 1/2" hole. Once all the holes are drilled, install the speaker and button. If your speaker does not have mounting holes, use hot glue to attach it to the top by running a bead around the speaker. For better adhesion, score a couple lines around the speaker.

· **STEP 4:** You will need to attach two wires to the speaker and two wires to the button as shown in Figure 14. Attach a two-pin female header to the opposite end of each of these. These headers will be used to connect to the modules.

· **STEP 5:** Attach the modules in the positions shown in Figure 14. The easiest way to mount the boards is with double stick foam tape. If you want to, you can drill holes in the Soundgin board and use machine screws to mount it.

· **STEP 6:** Attach a 1" MF standoff to a 1" FF standoff, then attach it to the base with a #6 machine screw. Do this with each of the four corners on the base.

· **STEP 7:** I used Schmartboard 5" and 7" jumpers to attach the modules. Refer to the boards, as well as the module documentation, for the actual locations.

Yellow 5" Jumpers
· Regulator + (header closest to the Carrier 1) to Carrier 1 + (closest to cap)
· Regulator - (header closest to the Carrier 1) to Carrier 1 - (closest to cap)
· Carrier 1 Port0 to SCP1000 CSB
· Carrier 1 Port1 to SCP1000 CK
· Carrier 1 Port2 to SCP1000 MOSI Carrier 1 Port3 to

SCP1000 MISO

Blue 7" Jumpers
· Regulator + (header closest to coax) to SCP1000 5V
· Regulator – (header closest to coax) to SCP1000 Gnd
· Regulator Vin (four-pin header) to Soundgin Power +
· Regulator Vss (four-pin header) to Soundgin Power –
· Carrier 1 Port9 to Soundgin IN (added header)
· Carrier 1 Port11 to Soundgin CTS (added header)

Speaker Header to Soundgin SPK header

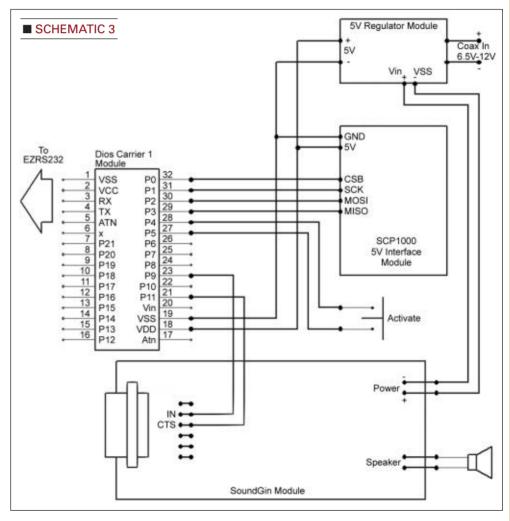Button Header to Carrier 1 Port4 and Port5

· **STEP 8:** Attach the top base to the

four standoffs with four #6 machine screws. You will want to attach some rubber feet to the bottom base so that the machine screws don't scratch anything. You can purchase these at most home centers. There is a part number listed for a set from Jameco.
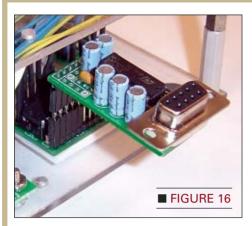
Testing the Pressure Talker

Apply power to the Pressure Talker by plugging an AC adapter into the voltage regulator. If the green LED does not light or is dim, then remove the power and recheck your wiring.

Plug the EZRS232 into the Carrier 1 by using a five-pin double header as shown in Figure 16. Install the free Dios compiler and connect the PC to the EZRS232 using a nine-pin straight cable. The DiosPro chip is already

■ SCHEMATIC 3

■ FIGURE 16

programmed with a test program, so once you run the compiler and power-up the Pressure Talker, it should display test data in the debug terminal.

• <u>TEST 1:</u> First, you need to test the pressure sensor by loading and programming the same Program 1. This will display pressure data in the debug window.

• <u>TEST 2:</u> Next, load up the program called PressureTalket1.txt. This program will say the word "Barometer" when started and will say it when the button is pressed.

Main Program

Load the program called Pressure Talker2.txt and program it into the DiosPro chip. Once programmed, the Pressure Talker will speak the indoor temperature and pressure each time the button is pressed. The pressure and temperature is constantly displayed in the debug window.

As in the previous project, at the very beginning of the program is a statement where I assign a constant called offset. This is a value that will allow you to change the absolute pressure value to the station pressure. This value is added to the absolute value. You should change this value so that your pressure gauge reads the same as your local forecast.

The Soundgin chip uses Allophones to define the speech. Each word that the Pressure Talker speaks is made up of these Allophones. They are defined as table entries at the beginning of the program. You may change these if you like. You can download special software from the Soundgin website and that will help you define these. Just make sure the table entry starts with a label and ends with a 0.

Use the SGplay command to display your new word by passing the label.

How Well Does it Work?

I recently took the Soundgin to RobotFest. About 50% of the individuals could not understand the voice. It does take a little getting used to. However, I will say that a couple of visually impaired individuals had no problems with the speech.

Updates and source code for these projects are available for download at **www.kronosrobotics. com/Projects/pressure.shtml**. **NV**

PARTS LIST

KRONOS ROBOTICS
❏ DiosPro 40 chip
www.kronosrobotics.com/xcart/customer/product.php?productid=16428

❏ DiosPro 28 Chip
www.kronosrobotics.com/xcart/customer/product.php?productid=16429

❏ Dios Universal LCD Carrier
www.kronosrobotics.com/xcart/customer/product.php?productid=16410

❏ Dios Carrier 1
www.kronosrobotics.com/xcart/customer/product.php?productid=16170

❏ EZRS232 Module
www.kronosrobotics.com/xcart/customer/product.php?productid=16167

❏ DiosPro 28 Starter Kit 2
www.kronosrobotics.com/xcart/customer/product.php?productid=16448

❏ 3.3V to 5V Interface Kit
www.kronosrobotics.com/xcart/customer/product.php?productid=16537

❏ 36-Pin Female Snapable Header
www.kronosrobotics.com/xcart/customer/product.php?productid=16291

SCHMARTBOARD
❏ Protoboard
www.schmartboard.com/index.asp?a=11&id=24

❏ 2" Jumpers

www.schmartboard.com/index.asp?a=11&id=112

❏ 3" Jumpers
www.schmartboard.com/index.asp?a=11&id=41

❏ 5" Jumpers
www.schmartboard.com/index.asp?a=11&id=42

❏ 7" Jumpers
www.schmartboard.com/index.asp?a=11&id=43

JAMECO
❏ 6-32 1" Hex Male/Female Standoffs — Four Needed (#77650)

❏ 6-32 1" Hex Female/Female Standoffs — Four Needed (#77578)

❏ 6-32 .5" Machine Screws (#42438)

❏ Rubber Feet (#651903)

❏ Push Button (#616850)

❏ AC Adapter 9V 500 ma (#100853)

OTHER
❏ Soundgin Development board. Available at **www.speechchips.com/shop/item.aspx?itemid=14**.

❏ Double Stick Foam Tape
Available at most home centers.

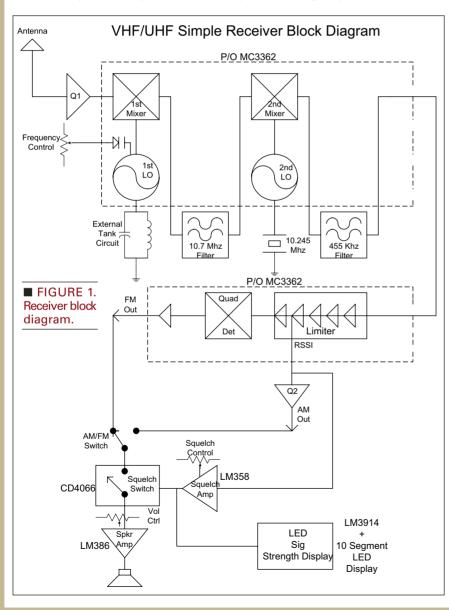❏ Acrylic (Plexiglas)
Available at most home centers.

WEB LINKS
■ Kronos Robotics
www.kronosrobotics.com/xcart/customer/home.php

■ SchmartBoard
www.schmartboard.com/mscva

■ Jameco
www.jameco.com

BY CHARLES IRWIN

A SIMPLE VHF
RECEIVER

Of course, it is always nice to add some desirable features. An antenna pre-amplifier stage, a signal strength display, a squelch control, a speaker amplifier, and a frequency band switch round out the design of this project.
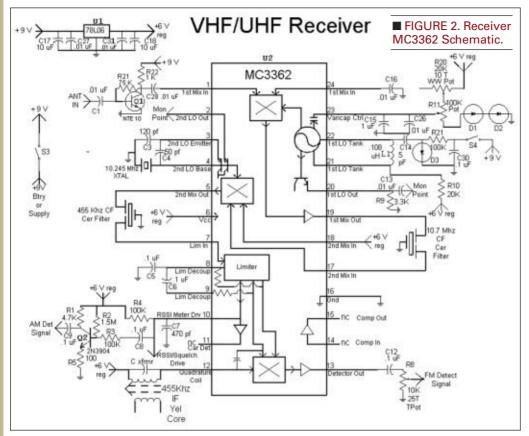
The receiver is able to receive amateur radio stations, police, emergency services, NOAA

This project was inspired by another *Nuts & Volts* reader — a teacher — looking for a receiver project for his class.

His requirements entailed a fairly simple receiver with a minimum of adjustments. Being an avid radio hobbyist, I came up with the following design using a Motorola narrow band FM receiver IC. This IC, the MC3362, is a double conversion, superhetrodyne receiver which needs only one tuned circuit. The variable capacitor for the tuned circuit is included in the IC as a built-in varactor diode. It is only necessary to add an external coil to the IC, plus some external capacitors and resistors to get a working receiver.

VHF/UHF Simple Receiver Block Diagram

■ FIGURE 1. Receiver block diagram.

VHF/UHF Receiver

■ FIGURE 2. Receiver MC3362 Schematic.

weather stations, and other public service stations in the range of 114 MHz to 180 MHz.

Tuning Basics

A block diagram of the complete receiver is shown in Figure 1, while Figure 2 shows the schematic for the MC3362 portion of the receiver. Figure 3 shows the schematic for

the audio, squelch, and S Meter display circuitry.

Please refer to the complete block diagram of the receiver shown in Figure 1. The signal from the antenna is fed into the antenna pre-amp stage (Q1), then directly into the first mixer stage in the MC3362 IC. The first local oscillator stage, also in the chip, generates the necessary injection frequency which is determined by the external coil and internal varactor in the chip. The capacitance across the coil is varied by changing the voltage input to the MC3362 IC's

internal varactor. The value of this capacitance (between 5 and 25 pF) is sufficient to tune over a 40 MHz range. My completed receiver tunes from approximately 140 MHz to 180 MHz using only the internal varactor in the MC3362. I added the capability to switch in an extra 5 pF capacitor across the tuning coil which resulted in a range from 114 MHz to 150 MHz.

Although I did not build any provision for frequency measuring, it would be simple enough to correlate the varactor input voltage with the frequency being received and construct a tuning dial to indicate the received frequency. Since the tuning used in my unit is over such a wide band, I added a fine tune control (10 turn, 20K ohm wire wound pot) to make it easier to tune into a desired signal. If a particular frequency range is desired, it would be simple enough to figure out the varactor input voltage for those frequencies, and build a voltage divider circuit to allow only tuning between those desired frequencies.
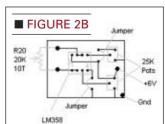
A simple circuit using an LM358 dual op-amp (shown in Figures 2A, 2B, and 2C — note Figure 2C is available on the *Nuts & Volts* website at **www.nutsvolts.com**) may be used to give a voltage range for a specific part of the receiver's bandwidth. For example, assume a frequency of 144 MHz is tuned when the input voltage to the varactor on the MC3362 is four volts, and a corresponding voltage for 148 MHz is 4.6 volts. (These voltages are used only as examples; voltages will vary between different MC3362 ICs.)

Adjust the 25K pot for a voltage of four volts at pin 1 of the LM358 op-amp, then adjust the other 25K pot for a voltage of 4.6 volts at pin 7. Now the 20K, 10 turn pot will easily tune

Specific Band Tuning Circuit

■ FIGURE 2A

■ FIGURE 2B

the receiver between 144 MHz to 148 MHz (the amateur radio two meter ham band). The lower band range from 114 MHz to 150 MHz allows monitoring of the aircraft band between 118 MHz and 136 MHz.

Demodulation Selection
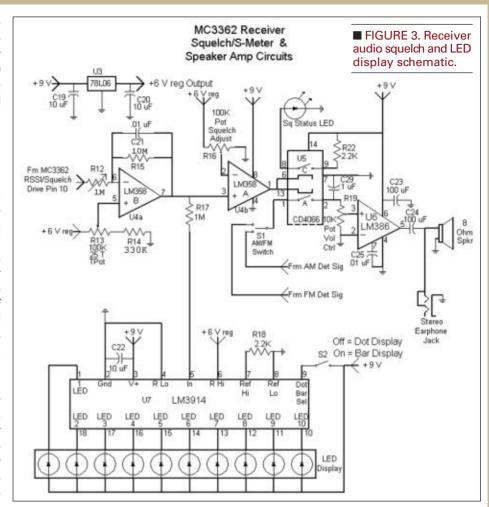
Since the aircraft band uses AM instead of narrow band FM, I used the RSSI (Received Signal Strength Indicator) signal to give an "AM" output. An external switch allows switching the speaker amplifier between the AM output of the chip and the FM output. Obviously, if one had some kind of VHF signal generator, it would be simple to calibrate the tuning controls on the receiver. Failing that, known frequency sources may be used.

To find the tuning range on the lower band, it is possible to use a digital FM receiver. Its local oscillator produces signals from 98.7 MHz to 118.7 MHz. Other known frequency sources are: NOAA weather stations around 162 MHz; amateur radio two meter band from 144 MHz to 148 MHz; and any local police or civil service VHF stations usually found above 150 MHz.

Referring back to the receiver block diagram, the output of the first mixer is either the input frequency plus 10.7 MHz or the input frequency minus 10.7 MHz. This image frequency could be eliminated by choosing a narrower frequency band and adding a band-pass filter for that frequency band between
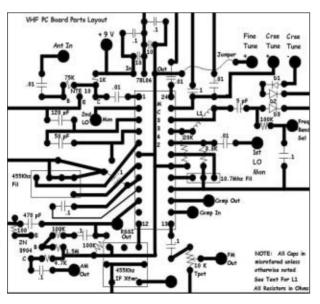
■ FIGURE 3. Receiver audio squelch and LED display schematic.

the input to the antenna pre-amp stage and the antenna. In my case, I decided to keep the wide tuning range and put up with the image frequency problem which means the

same station can be heard at two different tuning positions, 21.4 MHz apart.

■ FIGURE 5. Receiver audio squelch and LED display PCB parts layout.

■ FIGURE 4. Receiver MC3362 PCB parts layout.

+9v   LED DISPLAY Board

10 Segment LED Display

18 17 16 15 14 13 12 11 10
LM3914
1 2 3 4 5 6 7 8 9

Dot/Bar
Switch

10uF   1.2K

IN

+6V
Reg

The 10.7 MHz signal from the first mixer is then filtered through the external ceramic filter and fed to the second mixer. The second mixer has a crystal controlled oscillator built into the IC with only the addition of the 10.245 MHz crystal and a couple of capacitors needed. This mixing results in a 455 kHz output frequency.

The IC is designed to eliminate the image frequency by a steep rolloff of stage gain at that frequency (20.945 MHz). The 455 kHz signal is again filtered through an external ceramic filter and fed into the limiter stages of the IC. The MC3362 also has built in RSSI circuitry, which gives a logarithmic output corresponding to the input signal strength. This signal — since it reflects the input signal variations in amplitude — also allows using it as an amplitude modulation detector output. In addition, it provides the signal needed to control the LED S meter display, and also control the squelch function.

Finally, the output of the limiter (which has removed most of the AM signal components from the input signal) goes to the quadrature detector circuitry of the IC which needs only an external tuned circuit at 455 kHz to give an audio output for any narrow band FM signal received. That external, tuned circuit is easily done with a 455 kHz IF transformer, using only its primary winding. The audio output from both the FM detector and that derived from the RSSI signal is now available to be fed into the external speaker amplifier, as is the raw RSSI signal which can now be fed into the external squelch and signal strength circuitry.

Squelch And Signal Strength

The audio output from the AM detector is smaller than from the FM detector. To equalize them, a trimpot was used at the FM detector output.

The RSSI signal output voltage change is quite small and must be amplified; it must be referenced back to 0 volts to be useful for the squelch and signal strength display. That is readily accomplished with an op-amp which does the amplifying and the voltage level shifting in one amplifier stage. The second amplifier stage in the op-amp functions as a comparator to give a positive "on" voltage to switch the analog gate of the CD4066 on, allowing the audio signal to be input to the speaker amplifier and speaker. The squelch control pot sets the reference voltage at which the squelch will turn on, and can be adjusted for an input signal of any level, including a "no signal" level.

The adjustment of the squelch and signal strength level will be different for each IC. I tried two different MC3362s and found their RSSI output signals were completely different. One MC3362 had a no signal RSSI output of 5.38 volts which went down to 5.28 volts with a strong signal; the second one had a no signal RSSI output of 5.28 volts only going down to 5.26 volts with a strong signal. These differences can easily be handled by the gain adjustment and voltage level adjustment on the inputs to the op-amp.

The 10 segment LED display is controlled by the LM3914 IC which lights up each LED in direct relation to the voltage received from the op-amp stage described above. The lower reference for the LM3914 is ground (0 volts), and the upper level is the regulated +6 volt supply. The output signal from the op-amp is adjusted to swing between .6 volts (low or no signal) to six volts (strong signal). Each additional LED will light up as the voltage varies between .6 and six volts.

If the unit is powered with a nine volt battery supply, then it is better to operate the LED display in the "Dot" mode (only one LED on at a time). Otherwise, if one is using an AC powered, nine volt supply, the "Bar" mode makes a nice display with one LED on at no signal level, and all 10 of them on with a very strong signal.

■ FIGURE 8. Receiver inside view 1.

■ FIGURE 7. Receiver front control panel.

Using the Dot mode, the receiver draws 39 milliamps; while using the Bar mode, the receiver can draw up to 105 milliamps.

Construction

Figure 4 shows a parts placement diagram of the MC3362 PCB (printed circuit board). Figure 5 shows a parts placement diagram of the audio, squelch, and part of the S meter display drive circuitry. Finally, Figure 6 shows the parts placement for the LED display and LM3914 driver circuitry.

Figures 7 through 10 show various views of the completed receiver.

Figure 11 shows a photo of the only fabricated coil needed for the receiver. It is wound using 20 gauge enameled copper wire wound over the shank of a 7/32 inch drill bit. There are six complete turns which will be 1/4 inch in diameter after being removed from the drill bit. The turns are separated until the winding is 3/8 inch long. This coil is L1 as shown in the schematic diagram and parts placement diagram of the MC3362 PCB of the receiver. Note the leads on this coil are at least 7/16 inch long to insure it is at least 3/8 inch above the ground plane of the PCB.

There are .bmp image files available which can be used to create PCBs for this receiver project. These files are on the *Nuts & Volts* website and need to be printed at their original size to insure the mounting holes match the parts. Note the distance between IC pins is .1 inch, while the width between the IC pin rows is .3 inches.

After all three PCBs are completed and etched, the parts for the MC3362 PCB may be attached and soldered. Before installing the MC3362 IC, insure there are no shorts to any of the pins, and also insure the proper voltages appear at each pin. This can easily be determined by referring to the schematic of the MC3362 portion of the receiver.

Remove the power and install the

■ FIGURE 9. Receiver inside view 2.

MC3362 IC. Reconnect the nine volt source. There should not be more than a 10 to 15 milliamp current drain from the nine volt source. I recommend putting a 100 ohm resistor between the nine volt source and the power input to the PCB. If the voltage drops more than a volt into the PCB, then there is probably a short or a mistake on the board.
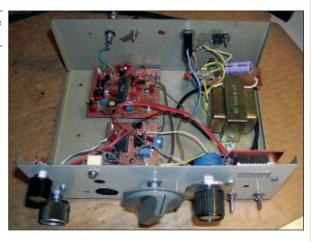
If all is working well, you should be able to hear a strong audio hiss from pin 13 of the MC3362. That is a good indication the board and IC are working. At this point, you may wish to connect the two tuning potentiometers (R11 and R20 in the schematics), and attempt to tune in a station. A good one would be the NOAA weather station in your area. They are usually at 162.4 MHz. I can easily receive the one in this area transmitting at 250 watts from Mt. Pisgah (western North Carolina).

I did not have to tune the yellow slug in the 455 kHz IF transformer; it worked well without any adjustments. If you feel the need to adjust it, without any signal, tune it for maximum hiss from the speaker, but not more than 1/8th of a turn either way.

Proceed with the parts placement and soldering of the remaining PCBs, carefully checking for shorts and correct voltage levels *before* installing any of the ICs.

The Parts List shows a
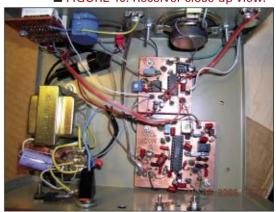
simple aluminum box, 6" x 5" x 4". However, you may wish to use something you already have on hand. I used a recycled box I had from a previous project. The placement of the PCBs is not critical, but insure that L1 is as clear as possible from any metallic surface. It will be a good idea to give yourself enough room to put a fairly large knob on the main tuning control since even a small movement of this control will tune the receiver across many MHz.

Once you have completed the mounting and connection of all the PCBs together, connect the nine volt power through a 24 ohm resistor. If there are no problems, you should see at least eight volts on the output to the receiver. With the squelch knob turned all the way counter-clockwise and the volume knob at its midpoint, you should be able to hear a loud hiss from the speaker. If you are satisfied that all is okay, then remove the 24 ohm resistor and connect the nine volt

■ FIGURE 10. Receiver close-up view.

■ FIGURE 11. Coil L1.

PARTS LIST

QTY	ITEM/DESCRIPTION

INTEGRATED CIRCUITS
- ❏ 1   MC3362/Lo-Power Dual Conv Nar Band FM Rcvr
- ❏ 1   LM386/Speaker Amp
- ❏ 1   LM358/Dual Op-Amp
- ❏ 1   LM358/Dual Op-Amp
- ❏ 1   CD4066/Quad Analog Switch
- ❏ 3   1N914/Lo-Power Silicon Diode
- ❏ 1   LM3914/8 LED Voltage Display
- ❏ 2   78L06/6 Volt Lo-Power Regulator
- ❏ 1   NTE 10/VHF/UHF NPN Transistor
- ❏ 1   2N3904/Gen-Purpose NPN Transistor

OSCILLATOR CRYSTAL
- ❏ 1   10.245 MHz Crystal

FREQUENCY FILTERS
- ❏ 1   10.7 CF Ceramic Filter
- ❏ Alt. 1 10.7 CF Ceramic Filter
- ❏ 1   455 kHz CF Ceramic Filter

IF TRANSFORMER
- ❏ 1   455 kHz (Yel Core)

HARDWARE
- ❏ 1   PC Bd Dbl Cu Clad
- ❏ 1   24 Pin DIP IC Socket
- ❏ 1   20 Pin DIP IC Socket
- ❏ 1   18 Pin DIP IC Socket
- ❏ 1   14 Pin DIP IC Socket
- ❏ 2   8 Pin DIP IC Socket
- ❏ 1   8 Pin DIP IC Socket
- ❏ 4   SPDT Toggle Switch
- ❏ 1   10 LED Bar Display
- ❏ 1   2" Speaker 8 Ohm
- ❏ 1   Bud Mini-Box 6" x 5" x 4"
- ❏ 1   Female Banana Jack
- ❏ 1   Male Banana Jack
- ❏ 1   3.5mm Stereo Jack Female
-         4-40 Nuts, Bolts (3/4"L), and Washers

VARIABLE RESISTORS (1/8 watt or greater)
- ❏ 2   100K Pot Linear
- ❏ 1   100K 25 Turn Trimpot Linear
- ❏ 1   10K 25 Turn Trimpot Linear
- ❏ 1   1M 25 Turn Trimpot Linear
- ❏ 1   25K 25 Turn Trimpot Linear
- ❏ 1   10K Pot Audio Taper
- ❏ 1   20K Pot 10 Turn Wire Wound

FIXED RESISTORS (1/8 watt or greater)
- ❏ 1   100 ohm
- ❏ 1   2.2K ohm

- ❏ 4   4.7K ohm
- ❏ 1   1K ohm
- ❏ 1   75K ohm
- ❏ 4   100K ohm
- ❏ 1   330K ohm
- ❏ 1   470K ohm
- ❏ 1   1M ohm
- ❏ 1   1.5M ohm
- ❏ 1   10M ohm

CAPACITORS (WV 10 volt or greater)
- ❏ 1   5 pf
- ❏ 2   50 pf (47 pf)
- ❏ 1   120 pf
- ❏ 1   470 pf
- ❏ 9   .01 µF
- ❏ 7   .1 µF
- ❏ 1   1 µF
- ❏ 5   10 µF
- ❏ 2   100 µF
- ❏ 1   LM358/Dual Op-Amp
- ❏ 1   LM358/Dual Op-Amp
- ❏ 1   LM386/Speaker Amp
- ❏ 1   CD4066/Quad Analog Switch
- ❏ 1   LM3914/8 LED Voltage Display
- ❏ 1   10 LED Bar Display
- ❏ 3   1N914/Lo-Power Silicon Diode
- ❏ 1   10.245 MHz Crystal
- ❏ 1   10.7 CF Ceramic Filter (Buy Fm OS Elec)
- ❏ 1   24 Pin DIP IC Socket
- ❏ 1   20 Pin DIP IC Socket
- ❏ 1   18 Pin DIP IC Socket
- ❏ 1   14 Pin DIP IC Socket
- ❏ 2   8 Pin DIP IC Socket
- ❏ 1   8 Pin DIP IC Socket
- ❏ 1   3.5mm Stereo Jack Female
- ❏ 4   SPDT Toggle Switch
- ❏ 1   1M 25 Turn Trimpot Linear
- ❏ 1   100K 25 Turn Trimpot
- ❏ 1   10K 25 Turn Trimpot Linear
- ❏ 1   25K 25 Turn Trimpot Linear
- ❏ 1   100 ohm
- ❏ 1   2.2K ohm
- ❏ 1   4.7K ohm
- ❏ 1   1K ohm
- ❏ 1   75K ohm
- ❏ 3   100K ohm
- ❏ 1   330K ohm
- ❏ 1   470K ohm
- ❏ 1   1M ohm
- ❏ 1   1.5M ohm
- ❏ 1   10M ohm
- ❏ 1   5 pf

source directly to the power input to the PCBs.

At this point, you are now ready to adjust R12 and R13, the squelch and LED display controls. Start with R12 adjusted for maximum resistance (1 megohm). Connect a two foot piece of stiff copper wire to the antenna connector, turn up the volume, and insure you are not receiving any signal. Now adjust R13 until the first LED is lit up on the LED display. Tune to a fairly strong station and adjust R12 until the sixth or seventh LED is lit up. Tune away from the station and insure the first LED is lit up.

You will notice these two trimpots are interactive; changing one will change the other. Eventually, you will have them adjusted so that the first LED is lit on "no signal," and the sixth or seventh LED is lit on a strong signal. There may be sections of the tuning range which will result in no LEDs being lit. This is not a problem, but merely shows those portions of the band are quieter than the one you initially used to make your adjustments. Turning up the squelch control with no signal will mute the speaker.

As soon as you are getting a signal, the speaker will activate allowing you to hear the station. For initial tuning, I suggest you turn the squelch all the way down (off) until you hear a station. Then you can adjust the squelch high enough to hear the station, but the speaker will mute when that station stops transmitting. Listening to that steady hiss all the time is very annoying, hence the addition of the squelch control.

Conclusion

This project is not difficult, but there is a lot of detailed work. It is best to carefully check each stage of your work before continuing to the next. I am sure you will be able to complete the project and enjoy your new VHF receiver.

As with all projects, this one could

Parts List continued ...

QTY	ITEM/DESCRIPTION
❏ 1	50 pf
❏ 1	120 pf
❏ 1	470 pf
❏ 9	.01 µF
❏ 7	.1 µF
❏ 1	1 µF
❏ 5	10 µF
❏ 2	100 µF
❏ 2	78L06/6 Volt Lo-Power Regulator
❏ 1	NTE 10/VHF/UHF NPN Transistor
❏ 1	2N3904/Gen-Purpose NPN Transistor
❏ 1	455 kHz CF Ceramic Filter
❏ 1	455 kHz (Yel Core)
❏ 1	PC Bd Dbl Cu Clad
❏ 1	2" Speaker 8 Ohm
❏ 1	Female Banana Jack
❏ 1	Male Banana Jack
❏ 1	Bud Mini-Box 6" x 5" x 4"
❏ 2	100K Pot
❏ 1	20K Pot 10 Turn Wire Wound
❏ 1	10K Pot Audio Taper
❏ 1	MC3362/Lo-Power Dual Conv Nar Band FM Rcvr
❏ 1	10.7 MHz CF Ceramic Filter (To Reach Min Order of $10)

be improved with the following:

1) Addition of a phase locked loop frequency control allowing exact frequency tuning in incremental steps.

2) Addition of a digital frequency readout display.

3) Addition of a scan control which will continuously scan the frequency band and stop upon reception of a signal.

4) A higher power speaker amplifier for use with larger speakers.

5) Addition of band-pass filters between the antenna input and the input to the receiver.

There is a terrific program for designing these filters available from Neil Heckt at **www.aade.com** Neil is also selling an excellent measuring instrument for measuring inductance and capacitance on his site — the L/C Meter IIB Inductance/Capacitance Meter. Along with this meter and the free software from his

NOTE

■ An extensive parts list, along with the PCB files, are available on the *Nuts & Volts* website at **www.nutsvolts.com**.

site, I designed and built a five pole bandpass filter for the 118 MHz to 136 MHz aircraft band. I also plan to build one for the two meter amateur radio band between 144 MHz and 148 MHz.

Of course, all these things will increase the cost and complexity of the receiver, but it would be interesting to design and add them to the receiver.

All the data sheets for each of the ICs, Q1, Q2, and a copy of the aircraft band bandpass filter are also available on the *Nuts & Volts* website. I welcome any comments, suggestions, or questions. **NV**

CONTACT THE AUTHOR

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You have probably heard someone say that some resistors are "noisier" than others. All resistors generate electrical signals.

Without power applied, most like-valued resistors generate about the same amount of noise at a given temperature.

This noise is mostly thermal or "Johnson" noise[1]. When power is applied, typically as a current flowing through the resistive material of a resistor, there can also be "shot" noise and other sources of noise including "1/f" noise, so named for its distribution over frequency. This 1/f noise can be attributed to internal resistor composition and connections between the resistive material (film, carbon composition, or resistive wire) and the resistor leads[2].

BUILD THE JCAN TO MEASURE RESISTOR NOISE

You may have literally heard the difference between resistor compositions while testing an audio pre-amplifier with different types of components. Or, if you work with high gain amplifiers used to measure signals, you might also be interested in resistor noise. It is usually of concern in small signal transistor or tube applications, as well as in op-amp circuits generally using two or more resistors. I recently started wondering how to measure the noise from a resistor. I wanted to measure it — in some common unit — just like an ohmmeter measures resistance.

I started my quest by placing various resistors on the input of my best meters that can measure small AC voltages. It didn't work. Next, I looked up resistor noise in several of my electronics books, including a few of the classic electronics texts. They all said, "It's easy, just use an amplifier." It still didn't work.

After several weeks of studying JFET and op-amp data sheets and several different circuit techniques, it turns out that it really is pretty easy, once you know the three problems that need to be solved and understand why they matter. Whether you are an audiophile, an instrument designer, an EE, physics student, or an electronics enthusiast, you might find these problems in measuring resistor noise interesting. You might even want to build a "JCan" (the "J" is for

Johnson) and try it out yourself!

The JCan is a very sensitive instrument that can measure resistor noise when used with a standard AC voltmeter capable of measurements in the range of 1-20 mVAC at audio frequencies. The JCan can also measure thermal noise plus shot noise by injecting a small current into resistors under test. All that is needed to calibrate the JCan is a small selection of resistors of known values. Once the calibration numbers have been determined using a relatively simple spreadsheet to analyze your raw data, the JCan can be used to compare different types of resistors. For example, under power, the difference between the noise generated by metal film resistors and carbon composition resistors is easy to measure.

Before considering the direct measurement of Johnson (thermal) noise, let's look at how small of a signal we are looking for. Johnson noise is defined by the following equation:

$$Vnoise = \sqrt{4 \times k \times T \times R \times BW}$$

or

$$Vnoise^2 = 4 \times k \times T \times R \times BW$$

where: k is Boltzmann's constant (~1.381×10^{-23}), T is the ambient temperature in Kelvin, R is the resistance of the resistor under test in ohms, and BW is the bandwidth

in Hertz being considered (the pass band of the preamp and meter combined). Most manufacturers specify thermal noise in "1 Hz bandwidth," which we can find by dividing Vnoise by $\sqrt{BW}$. The $nV/\sqrt{Hz}$ thermal noise for resistors at room temperature ranges from about 4 nV (nanovolts or 1×10^{-9}V) for a 1K resistor to about 58 nV for a 200K resistor. Over a bandwidth of about 20 kHz, the corresponding expected noise voltages range from about 0.6 µV for a 1K resistor to about 8 µV for a 200K resistor.

There are three crucial parameters that must be considered to successfully measure resistor thermal noise: (1) input sensitivity; (2) input capacitance; and (3) input noise.

Problem No. 1:
Most modern DMMs cannot directly measure µV AC voltages.

Notice that over a wider bandwidth of 300 kHz, resistor thermal noise voltages become larger, ranging from about 2 µV for a 1K resistor to about 32 µV for a 200K resistor. It would seem that with a very sensitive bench multimeter you should be able to directly measure resistor thermal noise.

For example, the HP/Agilent 34401A, 6-1/2 digit multimeter, has a 100 mV AC voltage scale with about a 300 kHz bandwidth. The scale is defined as 100.0000 mV; however, when a 6K resistor is connected to the input and the meter is set to AC volts, the DMM indicates 000.000 mV.

The reason is that this otherwise excellent DMM was not designed to measure AC voltage below about 1 mV. The HP/Agilent 34401A, however, is an ideal DMM to use with the JCan. (If you do use a 34401A, set the AC filter to "slow 3 Hz" — the meter response time, not the

■ JCan — top view.

input bandwidth — and four digits.)

Problem No. 2:
Some classic AC millivoltmeters can measure down to 10 µV, but still cannot directly measure resistor noise because of their relatively high input capacitance.

Next, we turn to a classic AC millivoltmeter such as the HP 400 GL. The 400 GL has a 0.1 mV scale (100 µV) that reads down to 10 µV. The bandwidth is 100 kHz with the internal filter switched on. This means that the 400 GL should be able to read a $\sqrt{Hz}$ signal of 10 µV/$\sqrt{100kHz}$ or to about $32\,nV/\sqrt{Hz}$; $41nV/\sqrt{Hz}$ is roughly equivalent to a 100K resistor. A 1/4 watt 100K resistor with short leads was tied under the input five-way binding posts of the 400 GL. A metal shield was then placed over the posts and connected to the common terminal (aluminum foil is okay, too).
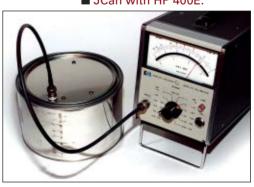
For a 100 kHz bandwidth, the 400 GL expected reading is about 13 µV. Although there seems to be some

indication, the actual reading is below 10 µV. The problem is that most analog AC millivoltmeters have an input capacitance on the order of 15 to 30 pf (picofarads). While that sounds small, when combined with 100K, it forms an input RC filter, limiting the bandwidth to about 57 kHz for an input capacitance of 28 pF; 57 kHz is far lower than the bandwidth of the HP 400 GL's 100 kHz filter bandwidth, which explains the low reading of about 9.8 µV, just below the 10 µV low end scale marking.

For higher value Rs, the bandwidth is further limited and the noise voltage becomes lower. Ironically, once input capacitance dominates, the thermal noise measurement becomes nearly independent of resistance. To directly measure noise voltage over a reasonable range of resistance values — such as 1K to 200K — very low input capacitance is essential. For bandwidth calculations, also note that the HP 400 GL bandwidth (with the 100 kHz filter turned off) is

■ JCan with HP 400E.

far higher than the specified 4 MHz bandwidth, often exceeding 10 MHz (albeit only "calibrated" to 4 MHz).

Problem No. 3:
Low input noise is important.

As I began to investigate pre-amplifier circuits, it quickly became apparent that just as input capacitance limits the high end of resistance values that can be measured, the amplifier's own input noise limits the low end. The thermal noise expected from a 1K resistor is about $4nV/\sqrt{Hz}$, therefore input noise must be lower than $4nV/\sqrt{Hz}$ to measure the thermal noise from a 1K resistor.

JFETs are among the most suitable transistors for use in a low capacitance, low input noise audio range preamp. The problem is that most existing designs — such as microphone amplifiers — are not suitable for use over a wide range of input resistances. Also, many of the classic low noise JFETs have a relatively high input capacitance rendering them less useful for the JCan preamp application. Some of our first JCan prototypes

achieved low input capacitance at the expense of relatively high input noise. These prototypes could only measure thermal noise down to about 10K.

Building the Circuit

A BF244A JFET transistor (for ultra low input capacitance) combined with a low noise LT1028 op-amp from Linear Technology was found to solve all three problems. A third op-amp stage further helps to shape the bandwidth and to provide enough gain so that most modern bench DMMs can be used with the JCan to directly measure resistor thermal noise. While in some analog designs there can be an advantage to using a linear power supply to limit power supply noise, here, batteries are a must. Two 9V batteries power the JFET, op-amps, and provide the current to observe shot noise plus thermal noise when comparing resistors.

Since we are measuring very tiny voltages, it is essential that the preamp be well shielded. A paint can provides the needed shielding[4]. A half gallon can from the Cary Company of Addison, IL that has the same diame-

ter as a one gallon paint can lid (but a height of only 4") works well for this experiment. I found that the "half can" is more convenient to work with on the lab bench. Standard safety rules apply when drilling holes in the lid. *Always use safety glasses!* I found that a high drill speed works best when cutting small holes in the tin lid. A step drill comes in handy for the 3/8" hole for the BNC connector. If you don't have a step drill, begin with a small hole and work up to the needed 3/8" final hole size. If your can has an epoxy interior coating, be sure to sand the epoxy off where the cover meets the can for good electrical contact.

The JCan preamp must be wired on a soldered proto board, printed circuit board (PCB), or perhaps dead bug wired (parts glued to a substrate with wires and components soldered between pins). The line-to-line capacitance on solderless breadboard is too high. (Geller Labs — **www.geller labs.com** — will offer a printed circuit board.) PCB graphics are also available for download from the *Nuts & Volts* website (**www.nutsvolts.com**) for do it yourself hobbyists to make their own PC cards.

We found that slit input posts to accept resistors under test can be made from connector jack inserts. For example, a gold solder socket intended for use in a D-sub connecter can work well. A solid #18 copper wire can be soldered to the jack and then soldered onto a PCB. Or, a PC hole can be sized to accept a jack directly soldered on the PCB. Make sure to align both slits so a resistor can be easily pushed into both test jacks.

The JCan circuit is relatively simple as to principle of operation. The input JFET allows a drain current of about 1 to 4 mA for the 10M; 0V DC bias gate resistor. C1 couples the thermal noise from a resistor under test into the first stage JFET amplifier. R2, the drain resistor, doubles as the input for the first stage LT1028 low noise amplifier. The net gain of both stages combined is on the order of 150 ± ~25. The BF244 drain current and net gain will vary among parts. Note that

even with a battery supply, the power to the BF244 stage is further filtered to isolate it from the other stages.

The BF244 stage, as well as the resistor under test are referenced to both electronics common (0V between the two 9V batteries) and the can shield ground. Electrical safely tip: *In most cases, the tin can will not be directly tied to a house common (earth) ground, so be very careful that nothing on your bench connects a high voltage to the can!*

The first bandwidth shaping takes place in the combined BF244 and LT1028 stages. R2 and C2 form a first high pass filter (the low end frequency) and R1 and C10 form a first low pass filter (the high end frequency). At the output of the LT1028, R3 and C3 form another low pass filter. C15 and R6 form yet another high pass filter.

The last stage provides an additional gain of about 19.5 ± ~2 (R7/(R3+R6)). The purpose of the U2 stage is to create a large enough output signal that most bench DMMs can take over to measure the output AC voltage representing the thermal noise of the resistor under test. Another low pass filter is created by C14 and R7 and a final low pass output filter is created by R9 and C4. Some op-amps might not be able to directly drive the capacitance of a coax cable to a DMM, therefore R9 also helps to isolate the cable capacitance from the op-amp output.

The BF244A (Q1) offers both very low input gate capacitance, as well as extremely low device noise. The BF244A also has a nice bias point of drain current for zero Vgs (gate voltage). The BF244B or BF244C have very different drain currents at zero Vgs (Idss) and therefore are not suitable for use in the JCan. It is possible to use a 2N4416A JFET with a smaller drain resistor, higher drain current, and slightly degraded performance but the pin-out is different (gate at the end of the package) requiring a little bit of lead bending. Note also that some of the classic ultra low noise JFETs that are often used in high end audio preamps have a relatively high gate capacitance (6 to 25 pF) and are not

suitable for use in this application. Also, there are few options for U1, the LT1028. It is crucial that U1 also have low voltage and current noise.

An AD797 also works for this stage. Also, the final U2 stage must have a sufficient gain-bandwidth product (GBW) for a relatively high closed loop gain (~ 20) and should be able to drive the capacitance of an output cable. The LT1357 is particularly well suited for this application. Note that if an op-amp with insufficient GBW is substituted for U2, the effective bandwidth of the JCan filter will be narrower than intended (about 20 kHz) with JCan filter performance modified by the op-amp rather than determined as intended by the filter RCs alone.

Testing

You can build and test the JCan one stage at a time, or build the entire circuit and then test in stages, or just power it up and see if the entire circuit works. Testing will largely depend on how much bench equipment you have available. First, place a shorting wire across the "resistor under test" jacks (but, not the upper current source jacks) to protect the JFET during initial testing.

The BF244 is not as ultra sensitive to handling as some of the older MOSFETs were, however, good static practice is still needed. This doesn't mean that you need a ground strap (unless you work in sneakers in carpeted rooms on dry days). The best static protection approach for using the JCan is simply to hold the can top first, then manipulate the next resistor under test into the test jacks while resting the edge of your hand on the can top. For best electrical safety, disconnect all other test leads while changing resistors under test.

Use the slide switch to remove the ±9V power when changing resistors under test. Also don't forget to turn off power at the end of testing, since the load current on the order of 10 mA is relatively high for a 9V cell (about 10 hours of total battery life is possible with only reasonable care,

such as not leaving the JCan powered over night). JCan performance is not particularly dependent on battery voltage, so regulation and initial change in battery voltage during normal discharge is not of concern.

We use a relatively expensive C&K switch because it slides very easily and has high reliability contacts rated at 100,000 cycles. A more modest switch can suffice; just be sure it doesn't add noise by introducing intermittent contacts. Also, I found that removing the battery contacts to switch power is impractical since the snap contacts failed relatively quickly with repeated use.

If you have an ammeter handy, begin by connecting each battery one at a time and checking the load current. Up to about 17 mA is okay; much higher might indicate a short. It also might be good to first check from each battery snap terminal to common using an ohmmeter before connecting either battery to check for inadvertent short circuits.

Next, check the bias point of Q1 using a DC voltmeter. There should be about four to five volts across the drain and the source (V_{ds}). If not, replace R2 with a slightly higher or lower valued metal film resistor until this V_{ds} is achieved.

The following tests are optional; you may also proceed directly to Calibration and skip these tests. If you have a signal generator that can output 1 mV AC (either directly or with an attenuator such as a pad), you may want to test the combined BF244A/LT1028 stage. Unplug U2 for this test. Place a 50 ohm resistor in the resistor under test jacks — it presents a conveniently matched load for many types of signal generators. If your generator has another output impedance rating — such as 600 ohms — simply use that value resistor in the resistor under test jacks when making measurements with the signal generator.

Remember that the calibrated output value set displayed on many modern signal generators is for an output terminated as a matched load. Apply a 1-10 mV AC RMS test signal between

2 and 5 kHz to the input side of C1. The output voltage at U1, pin 6 or the node of R3 and C3 should be about 150 mV to 1.5 V AC RMS (± 20%).

To test the LT1357 U2 stage, unplug U1 and apply 1-10 mV AC RMS between 2 and 5 kHz to U1 pin 6. An input matching resistor (appropriate for your generator) can be spanned between U1, pin 6 and the TP1 common or U1, pin 3. You should observe about 20 times the input, or 18-180 mV (± ~10%) at U2, pin 6 or at the node of R9/C12. Note that while high level signal testing can be done with the can open (if your bench is not too noisy), for all actual noise measurements the can shield needs to be fully closed.

Calibration

Next, we calibrate the JCan for resistor noise. The good news is that the thermal noise from like valued resistors at zero current is about the same. Obtain a selection of several values of 1/4 watt metal film resistors from about 1K to 200K. One at a time, measure each resistor with your ohm-meter (or just read the printed value) and slide it into the resistor under test (RUT) posts in the JCan. I found it helpful to tape a label across each resistor as a tag with the resistor value. That way it was easier to read the value, and the tag doubled as a "pull" to help remove it from the test posts.

Close and lightly seal the JCan cover. Record the AC voltage as measured by a bench DMM, analog AC voltmeter, or an oscilloscope. It will be more difficult to make the measurements with an oscilloscope, but if that is the only instrument available to measure AC signals in a range of about 1 to 20 mV, go ahead and use it. It might work well to view an older analog CRT trace on a slower sweep speed and then divide the peak-to-peak voltage by a factor of about five.

Enter your R values and measured output voltages into an Excel spreadsheet or manual work sheet. (An Excel template can be downloaded from the *Nuts & Volts* website.) Note that the

posted worksheet corrects the resultant thermal noise curves for the thermal noise floor of the JCan as the measured output value for a shorted input resistor under test. The worksheet also corrects the high end resistance values for the effective parallel resistance of the 10M JFET bias resistor. The calculated theoretical values for $\sqrt{Hz}$ thermal noise for each value use the well-known Johnson thermal noise equation:

$$Vnoise = \sqrt{4 \times k \times T \times R \times BW}$$

The JCan output for a shorted input should be on the order of 1 mV. Short the input posts and take a reading of your noise floor. Your measured noise floor can be directly plugged into the posted spreadsheet as the noise floor value in mV. To estimate the actual noise floor at the input, after later determining the JCan gain and effective noise bandwidth, return to this step and divide the noise floor at the output BNC (about 1 mV) by $\sqrt{BW} \times Gain$, where BW is the effective noise bandwidth and gain is the gain you measured with a 1 mV ACV RMS test signal at about 2 kHz. You can also estimate the amplifier noise by your measured data at the low end of the scale. The noise of the JCan front end circuitry adds with the resistor noise as a sum of the squares, or Solving for the JCan input noise:

$$V_{JCanOutput} = \sqrt{V_{Rnoise}^2 + V_{JCanInputnoise}^2}$$

There is some part-to-part variation in

$$V_{JCanInputnoise} = \sqrt{V_{JCanOutput}^2 - V_{Rnoise}^2}$$

JFET parameters, however with reasonably good construction practice, it should be possible to achieve an input noise value from about 2 to $4\,nV/\sqrt{Hz}$.

Plotting Data Without a Gain Measurement

If you do not have easy access to

a signal generator, pick one entry in a range of about 10K-50K. Enter your total circuit gain into the gain number and your expected effective noise bandwidth (nBW) into the nBW cell or manually calculate the noise value by dividing the measured value by ($\sqrt{BW} \times Gain$) to calculate the $\sqrt{Hz}$ noise value. Now adjust either the effective noise bandwidth or gain or both numbers until your experimental curve falls directly over the theoretical curve. Using this technique only the product ($\sqrt{BW} \times Gain$) is defined, but that is good enough to be able to achieve a basic JCan noise calibration.

Plotting Data with a Gain Measurement

Terminate your input (RUT) with a suitable value for your signal generator. Apply 1 mV RMS at about 2 kHz to the input. Adjust the frequency slightly up and down to find the frequency at which you achieve peak gain (typically on the order of x2,600 to x3,200 or 2.6 to 3.2 VAC RMS) at the output for a 1 mV test signal. Enter the recorded gain number as the gain on the spreadsheet. Next, adjust the nBW number until the measured curves fall directly over the theoretical data at a mid resistance range of 10K-50K.

The (nBW) of a filter is equivalent to a "brick wall" filter of a flat gain and infinitely sharp roll off. The effective noise bandwidth is dependent on the shape of the frequency response of the actual filter and is not determined by the -3 dB point so commonly used to describe the voltage response with frequency. In fact, the effective noise bandwidth is determined using V^2, or power. Also, note that noise measurements do not necessarily require a steep filter response. It is only important that one be able to define the nBW for a given filter in terms of the equivalent brick wall filter.

If all has been done correctly to this point (by first measuring the JCan gain), the number you have just arrived at is the effective noise bandwidth of the JCan itself. This method of measur-

ing nBW using only a small selection of resistors and a single gain measurement is far easier than more traditional techniques. One such method for determining the nBW of an audio filter is described in the sidebar.

If the experimental noise curve is lower on the high side of the resistive scale (80K-200K), it might mean that the input capacitance is too high. Note that we compensated for the effective parallel 10M bias resistor on our noise spreadsheet by recalculating all of the input resistances before doing the final noise calculation.

Once the input capacitance causes the bandwidth to fall below the designed effective noise bandwidth of approximately 20 kHz, the output voltage falls below that expected for a given resistance value under test. With good input circuit construction, it should be possible to accurately measure resistor noise out to 100K-300K full scale.

Our typical assembled JCan units have been found to have a total input circuit capacitance on the order of 3 to 4 pF. A socket initially used for Q1 was removed and replaced by pin jacks because the dielectric constant of the plastic in the socket added over 2 pF directly to the input capacitance.

Comparing Different Types of Resistors Under Power

Once the JCan is running and calibrated, it can be used to compare different types of resistors under a small test current. Locate a few sets of different types of resistors (preferably pairs of same resistance values). Try to include in your test group at least some old type carbon composition resistors. Note that it doesn't work to simply connect V+ to a single resistor under test. The problem is that for the AC input circuit, a resistance from V+ to the input capacitor is considered in parallel with a resistor under test from the gate capacitor to common. Thus, connecting V+ to a single resistor under test looks to the JFET gate like a short or near zero resistance!

How to Independently Measure the JCan Effective Noise Bandwidth

This independent test is an advanced measurement that can provide an independent determination of the JCan effective noise bandwidth (nBW). This measurement is not necessary for calibrating a JCan for basic noise measurements, which can be done using only a selection of resistors and the noise work sheet alone, or using a selection of resistors, a gain measurement, and the noise work sheet giving an additional determination of the nBW of the JCan.

The following procedure outlines the way we verified the operation of the JCan while developing and testing the project. To make this measurement, you will need a digitally controlled signal generator (or a counter monitoring a non-digital readout unit). Begin by setting the output signal level (possibly with the aid of an inline attenuator) to exactly 1.00 VAC RMS at your peak response frequency, probably about 2 kHz.

Starting at the lowest frequency on our spreadsheet, record the output voltage. (Note that if your input voltage is not constant with frequency, you will need to reset it at each frequency.) Enter the voltage into the voltage column. After all the data has been entered, notice that the spreadsheet squares each voltage number, then multiplies the average of that number and the one before it times the frequency interval. This results in a "piecewise integration" of the power curve.

A sum of all these slivers (a sliver is the thin vertical "slice" between each frequency value) of area under the curve is the effective bandwidth of the filter. Also, note that a setting of other than 1V AC output can be used by determining the peak output voltage and adding it into your calculations. There will be a technical note at **www.gellerlabs.com** discussing effective noise bandwidth in more detail.

To make the "power on" measurement, connect two same type, same value resistors in series. Connect a wire to the center tap (or lay out your test jacks) so the C1 JCan input connection is connected to the tap between the two resistors. The other end of one resistor goes to the same JCan input common jack used in calibration. The other end of the second resistor goes to +9V filtered power.

Note that for these tests, the value of R is the parallel combination of both like valued (same type) resistors. You should now see noticeably higher fluctuation in the output voltage since you are now looking at thermal noise plus resistor noise caused by current flow through the resistor. The additional noise includes shot noise as determined by the equation:

$$Inoise = \sqrt{2 \times q \times I \times BW}$$

where I is the test current, q is the

Parallel and Series Resistors Under Test

Parallel and series combinations of resistors can also be tested. For a parallel combination, slide two 1/4 watt resistors into the slotted test jacks; for series connections, twist the ends of two resistors together or tack solder them. For larger leads, tightly wrap (like wire wrap) a small diameter wire on the end of the large lead to be able to slide it into the slotted test jack.

Notice that the noise from these combinations is the same as the noise expected from the equivalent resistance. At first glance, this seems counter intuitive since noise adds as the square root of the sum of the noise sources. The reason is that the measured output voltages are already representative of the mean square noise signals (noise power) and not the actual noise currents or voltages. The mean square signals are additive:

$$V_{JCanOutput} \propto \overline{V}^2_{TotalInputNoise} \times Gain_{JCan} \propto \overline{V}^2_{R_1} + \overline{V}^2_{R_2} + \overline{V}^2_{JCanInput\ noise}$$

charge of an electron, and BW is the effective noise bandwidth of the JCan and resistor "1/f" noise.

We use V+ filtered as the source of current for testing resistors under power. To test at a yet higher current, you could add a third 9V battery connected between V+ filtered ("V+ filt." on the schematic) and the positive side resistor under test for 18V. Don't go higher than 18V for powering the high side resistor under test, because even with the input capacitor, transients caused by connecting the resistors under test might damage the JFET.

If you are able to compare metal film resistors to carbon composition resistors, you can see that the noise is noticeably higher for the carbon composition resistors. One way to plot the noise data is to place colored dots on the calibration curves representing low and high fluctuation values for different types of resistors above the thermal noise for each resistor value on the resistance axis.

Another interesting experiment would be to see if you can detect the relatively small changes in noise with temperature. Usually to measure temperature, it is desirable to use a sensor with a relatively high rate of change of some measured parameter (usually resistance, voltage, or current). The opposite is true for resistor thermal noise, since thermal noise is proportional to $\sqrt{T}$, however, it should still be possible to measure changes in noise for changes in resistor temperature.
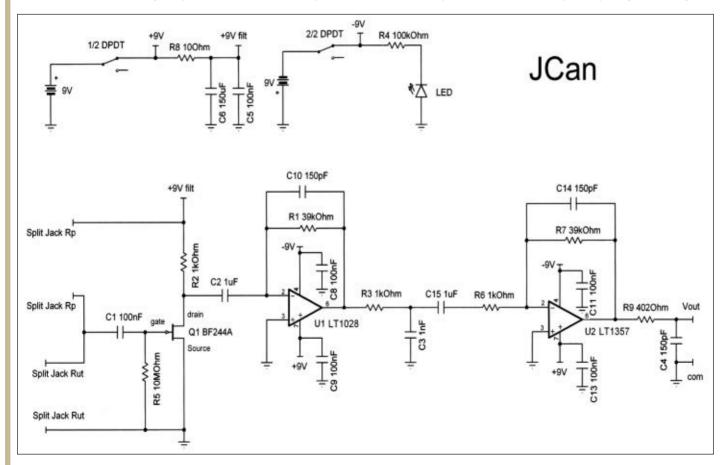
The easiest way to see the effect of a heated resistor — albeit at some risk to the fingers — is to heat a resistor and then plug it in, close the can, and observe the noise voltage drop as the resistor cools. If you use another resistor or a heat pump to heat or cool the RUT, you must remove all wires on the can before making the noise measurement. Otherwise, noise pickup from the heating or cooling wires acting as antennas can disturb the results.
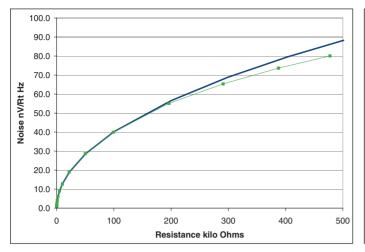
It is also probably not practical to heat the entire can, since the additional temperature effects on amplifier

bandwidth and gain caused by the temperature coefficients of the amplifier resistors and capacitors would be difficult to determine. Another complication of temperature testing is to consider the temperature coefficient of the resistor, or its change in resistance with temperature, which also shifts the thermal noise voltage.
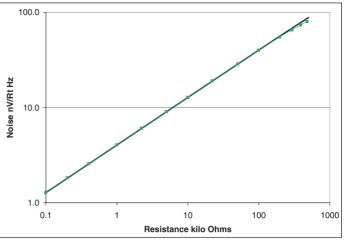
The JCan circuit might also be useful in other applications. As is, another circuit under test can be placed in the bottom of the JCan to make µV measurements on the second test circuit. Or, with some modifications, the Q1/U1 stage could be built into a small package for use as an active µV probe (long leads from the JCan would add too much capacitance). Yet another idea from Bill Jones, K8CU, is to reconfigure the RC filters for use as a low frequency, low capacitance antenna preamp for use with a short wire or whip antenna.

An interesting experiment would be to investigate the upper frequency limit of the preamp stages. With good

PARTS LIST

ITEM	QTY	REFERENCE	VALUE	DESCRIPTION
☐ 1	1	Q1	BF244A	Mouser 512-BF244A, Fairchild N-Channel JFET (you might want to buy 5 to 10 to observe differences between production JFETs).
☐ 2	1	U1	LT10281	Linear Technology Ultra low noise op-amp, Digi-Key LT1028CN8-ND, or Analog Devices AD797, Digi-Key AD797AN-ND
☐ 3	1	U2	LT1357	Linear Technology high speed op-amp, Digi-Key LT1357CN8-ND
☐ 4	1	Q1 Socket	Socket	Use pin sockets, same as item 14; a conventional transistor socket adds too much input capacitance.
☐ 5	2	U1,U2 Socket		Mill-Max DIP Low Profile, Mouser 575-193308
☐ 6	4	J1,2,3,4 Slit Socket		AMP gold #18 solder D-sub socket, Mouser 571-665693
☐ 7	1	R5	10M	We use Vishay VR25 BCC 5043D metal film resistor in our kits and assembled JCan, Mouser 594-5043DM10M00J (available only in large quantities). Also, RN1/4T1 1% 9.76M metal film, Allied Electronics 832-1111 or any other near valued 10M resistor (8M-10M, preferably metal film).
☐ 8	3	R2,3,6	1.0K	1% metal film, Xicon 1/4W (Mouser), For ex: Mouser ME271-1.0k (or, test and select for a V drain to source of about 4 or 5 volts).
☐ 10	2	R1,7	39.0K	1% metal film, Xicon 1/4W (Mouser)
☐ 11	1	R9	402 ohms	1% metal film, Xicon 1/4W (Mouser)
☐ 12	1	R8	10 ohms	1% metal film, Xicon 1/4W (Mouser)
☐ 13	1	R4	100K	1% metal film, Xicon 1/4W (Mouser)
☐ 14	9	Pin Sockets	SIP	We use a gold MILL-MAX pin jack, PN 0501-0-15-15-30-27-04-0; SIP type breakaway sockets, such as Mouser 575-643166 or equivalent, can also be used for R2, Q1,TP1,TP1 common, Vout, and Vout common.
☐ 15	2	C2,15	1 µF	Panasonic film capacitor, ECQV1J105M, Digi-Key P4548-ND
☐ 16	1	C1	0.1 µF	Panasonic film capacitor, ECQ-V1H104JL, Digi-Key P4525-ND
☐ 17	1	C3	0.001 µF (1nf)	Panasonic film capacitor, ECQ-B1H102JF, Digi-Key P4551-ND
☐ 18	3	C4,10,14	150 pf	AVX ceramic capacitor, 150 pf, 100V 10%, Digikey 478-3166-ND
☐ 19	5	C5,8,9,11,13	0.1 µF	Kemet ceramic, Mouser 80-C315C104M5U
☐ 20	1	C6	150 µF	Nichicon 150 µF, 50V, low impedance electrolytic, Mouser UHE1H151MPD
☐ 21	1	PCB		Geller Labs JCan PCB, www.gellerlabs.com
☐ 22	1	1/2 Gallon Paint		30W12A 1/2 Gallon "Short" Tin Can w/ Lid Unlined, 6-5/8" x 4", The Cary Company, 1195 W. Fullerton Ave., Addison, IL 60101
☐ 23	2	9V Battery Clips		Digi-Key 2240K-ND or equivalent
☐ 24	2	Double-sided Tape		3M 4013 1/2 wide foam mounting tape
☐ 25	2	Alkaline 9V Batteries		Rayovac 9V2 A1604-2 or equivalent
☐ 26		Resistors Under Test		A selection of metal film resistors from about 1K to about 300K for calibrating the JCan. We use the following collection in our "cal. pack": 49.9, 100, 200, 400, 1K, 2.2K, 4.9K, 10K, 22K, 49.9K, 100K, 200K, 300K, 402K, 499K. The exact values are unimportant. Actual values measured with an ohmmeter can improve your calibration data.
☐ 27		Resistors Under Test		A selection of different types of resistors, preferably in the range of 10K to 100K, such as carbon composition, carbon film, metal film, and wirewound for testing and comparing noise levels under power (one

ITEM	QTY	REFERENCE	VALUE	DESCRIPTION
				resistor to V+ filtered and a like type and valued resistor from input to common); we use 82K to extend battery life.
☐ 28	4	4-40 Standoffs		General-purpose hardware (if you experiment with nylon, note that paint can common is made through one of the conductive metal corner posts).
☐ 29	4	4-40 Screws		General-purpose hardware
☐ 30	4	4-40 Nuts / Lock Washers		General-purpose hardware
☐ 31	1	DPDT Slide Switch		ITT (formerly C&K) 1201M2S3CBE2, Mouser 611-1201M2S3CBE2 or equivalent, 100,000 cycles, has an easy slide action.
☐ 32	1	BNC		AMP BNC bulkhead solder jack connector, AMP 31-10-RFX, Mouser 523-31-10-RFX
☐ 33	1	LED		Any LED visible at about 50 to 100 µA (to save battery life), some ultra brightness types work well.
☐ 34	1	RG-174		Short length of coaxial cable or (short) twisted wires made from the excess ends of the 9V battery clip wires

different types of resistors under power is interesting to look at. The 1/f noise component can be directly seen as indicated by higher levels at the lowest frequencies.

Conclusion

We focused on building, testing, calibrating, and using a JCan to measure resistor thermal noise in this article. We touched on shot noise, using a small bias current to show the differences in noise between different types of resistors, such as metal film and carbon composition. We were not, however, able to provide a thorough or comprehensive introduction to the topic of noise, including Johnson thermal noise (white noise), 1/f "flicker" noise generally attributable to semiconductor crystal structures, or shot noise caused by current flow. A list of references on noise theory and application will be posted on **gellerlabs.com** including textbooks, articles, and web published university experiments, and semiconductor manufacturer tech notes. **NV**

construction, the Q1 stage can perform out to 10 MHz, but the op-amp stages are limited to far lower frequencies by their open loop gain as a function of frequency.

Several people who tested the JCan design for us suggested listening to the output with an audio amplifier. Also, if you have a spectrum analyzer or digital oscilloscope with an FFT function, the noise spectra between

JCan Noise Worksheet — LT1028 / LT1357

Legend:	Data Calculated by WrkSht	JCan calibration data	Entered Data

Enter Resistor Under Test (k ohms)	Corrected R for input R	Theoretical 1 Hz NBW nV calc	Measured Data JCan Vout AC mV	JCan Vout AC mV corrected for input noise	1 Hz NBW calculated from JCan Vout nV / Rt Hz calc		Enter JCan Gain	Enter JCan Bandwidth
							3207	21234
0.052	0.05	0.9	1.14	0.4	0.9			
0.1	0.10	1.3	1.22	0.6	1.3			
0.1997	0.20	1.8	1.36	0.9	1.8		Input R kilo ohms:	10000
0.4003	0.40	2.6	1.60	1.2	2.6			
0.9962	1.00	4.0	2.17	1.9	4.1			
2.216	2.22	6.0	3.02	2.8	6.1		Input Noise (mV at output)	1.06
4.973	4.97	9.0	4.36	4.2	9.0			
9.975	9.97	12.8	6.06	6.0	12.8			
21.92	21.87	18.9	8.96	8.9	19.0		Temperature degrees F	72.5
50.26	50.01	28.6	13.43	13.4	28.6			
99.92	98.93	40.2	18.69	18.7	39.9			
200.1	196.17	56.6	25.78	25.8	55.1		Calculated Temperature	
299.6	290.89	68.9	30.56	30.5	65.4		Centigrade	22.5
403.3	387.67	79.5	34.43	34.4	73.6		Kelvin	296
501.5	477.55	88.3	37.44	37.4	80.1			

REFERENCES

■ 1) J.B. Johnson, "Thermal Agitation of Electricity in Conductors," *Physical Review*, vol. 32, July, 1928, page 97.

■ 2) Horowitz and Hill, "The Art of Electronics," Cambridge University Press, 1986, Section 7.10, "Origins and Kinds of Noise," pages 288-290.

■ 3) Ibid., Section 7.20, "Bandwidth Limiting and RMS Voltage Measurement," page 306.

■ 4) B. Klein, N. Albaugh, "Analog eLab: Amplifier Noise: Types, Origins, Magnitude Predictions and Reduction Techniques," March, 2005, a TI Webcast at **www.ti.com**.

the spark to ground with the electronics running on hot to neutral. True, the ground and neutral get connected at the box, but it made all the difference in the world for my stove. To power my furnace with a small inverter, I ran wires right over to the breaker box and got a neutral and a ground. Works good with a modified sine wave output. Running with a deep discharge marine battery that also powers my pellet stove. (Check your local Interstate Battery Co. for blems. Got my blem 80 amp hr. battery for $40.

— **Ruth Tyndell**

MAGNETIZED OVER TURNS

I was reading in the Q&A column about the flywheel re-magnetizer. You say "you will need 88 volts to drive 27 amps through the six series coils." It seems to me this will provide 162 ampere turns of energy. The other re-magnetizer designs I have seen seem to be more in the range of 10,000-20,000 ampere turns of energy. They use thousands of turns of wire rather than six turns.

How can this circuit provide enough energy to re-energize the magnets? Also, the person who asked this question in the magazine said that he was using six of these electro-magnets at the same time. Wouldn't the six magnets all work against each other and cause problems?

— **Rex Anderson**

Response: Thanks for the feedback!

From your experience, it appears that Mr. Schallot's problem is not enough turns on the coil. My answer was designed to give a better way of obtaining the same ampere-turns, not knowing what was required. I don't see a problem in powering all six magnets at the same time, as long as every other one is reversed so they don't try to cancel each other.

— *Russ Kincaid*

PLUGIN' IT, PLUGIN' IT

I've been a subscriber for almost a year. I have little electrical background other than a basic circuits and electronics course I took in my college days in the late 70s! I remember back then working on some projects from *Popular Electronics*. Recently, my son has been involved in the FIRST robotics program. As a mechanical engineer, I mentored students working on the drives platform. I spent a lot of time, however, looking over the shoulder of the software guys. This sparked an interest in electronics from my college days. I started with the Mims books. *Make Magazine* also featured several electronics articles. I found my way to *Nuts & Volts* from one of the *Make Magazine* links so, you can thank those folks for the lead!

I read each issue pretty much cover to cover. Some of the articles I can't make it past much more than the first few paragraphs, while some of the projects I have been able to complete. Being interested in robotics as a start, I have thoroughly enjoyed the series on

robotics. I also read anything you have on microcontrollers. The authors have been extremely helpful. I have sent Chuck Hellebuyck several emails regarding how to get started with microcontrollers and programming. The three part series by Ron Hackett fit the bill for my level of knowledge. I followed along with Ron's projects and have completed those. That was a great jump start for me. That opened up a whole new forum, literally! The PICAXE Forum is a great place to learn and get questions answered.

I have also enjoyed the Near Space series. Although this is something I would like to pursue after I get some more fundamentals with circuits, I have purchased my ham radio license manual and plan to get my first level license this year!

I also pay close attention to the project articles. Not only the theory is good, but the practical examples of circuit building, connectors, stripboards, tools, etc. I have found a ton of good info here. The parts listings are a blessing. I have used many of the parts listed in those parts lists! It is a good place to start looking for options.

I have also found many good suppliers in your advertisements. Let those folks know it works! Many of those websites are full of good information, articles, tips, and other links, as well as some unique parts.

I just wanted to send a note to thank you for a great magazine and put a plug in for some of the authors!

— **David J. Pollatta**

EZ ICONS

I enjoyed Michael Simpson's latest article on the weather station, but he seems to have skipped over how to actually draw the icons on the screen. Is that information available other than embedded in the code?
— **Steve Gunsel**

Response: The ezLCD has an extensive command set. The DiosPro chip has an advanced library that utilizes these commands. Download the source files at the provided link and look at each subsection as outlined in the article. I made use of the following commands to build all the weather icons:
ezLCDPRINTXY
ezLCDCIRCLE
ezLCDCIRCLEFILL
ezLCDBOX
ezLCDBOXFILL
ezLCDHLINE
ezLCDLINE
These DiosPro library commands map pretty close to the actual ezLCD interface commands.
— *Michael Simpson*

LUB-DUB LOW DOWN

I enjoyed the recent article on building a device to measure the delay between heart beat and peripheral pulse. I think Gerard Fonte's comment on the "Lub-Dub" heart sounds as they relate to the sensing of the wrist pulse deserves some further discussion.

The "Lub" is the sound of the mitral valve shutting at the start of the left ventricle contraction when the ventricular pressure is rising. The "Dub" is the sound of the aortic valve closing as the ventricular pressure is falling below that of the aorta at the end of ventricular contraction.

Medical students spend much time learning to identify these and other valve opening and closing sounds, as well as their variations. It is complex, and when auscultating the heart the sounds are very variable depending on stethoscope position, body position, age, and normal and pathological conditions.

A possibly more accurate way to measure pulse delay would be to 'start the clock' with measuring the electrical signal as the left ventricle begins contraction (the 'q-wave' of the electrocardiogram). One of your advertisers (**ramseykits.com**) sells an ECG monitor which basically amplifies the millivolt heart signals. Also, *Scientific American*, in its now defunct "Amateur Scientist" column (available in their archives), has a great article and discussion of a home built ECG.

As a possible future project, you might consider a clinically useful related device — a peripheral pulse pressure measurement. Replace the electret microphones with sensitive pressure detectors. By measuring the pressure in the upper arm compared to the pressure at the thigh and ankle of each leg, you can detect the presence of peripheral vascular disease (narrowing of the arteries) which, in severe form, can lead to gangrene and amputation. Anyway, I enjoyed the article. As you might surmise, I am an Internist (retired).
— **Alan Rutner PhD, MD**

Response: Thank you for your comments on my article. Naturally, I agree with all of your statements and suggestions.

However, you need to note that the limitations placed on any article for Nuts & Volts *mean that any project must be simple and short. Many of the medical and technical aspects had to be simplified and/or eliminated. The project, as presented, is much more of a toy than a medical instrument. As a design engineer with a Masters in Natural Science (biology) and interests in bio-medical applications, I had two reasons for writing the article. The first was to present a simple project that used some different technical details. The second was to float an idea to the medical community.*

It seems to me that a simple and inexpensive device that directly measures peripheral vascular disease would be a useful tool. Additionally, the idea that the peripheral pulse shape might be directly linked to peripheral vascular disease is something that I am not aware of in the literature (that doesn't mean it isn't there). Perhaps you have more information than I do. Anyway, I always appreciate getting feedback from readers. (The positive kind is preferred.) Thank you for your interest and kind words.
— *Gerard Fonte*

IN THE SPOTLIGHT

An Interview with Sharon Shepard

Director of Sales and Marketing at Integrated Ideas and Technologies, Inc.

by Marvin Mallon

This month's spotlight is on Integrated Ideas and Technologies, Inc., a privately owned fabrication firm located in Coeur d'Alene, ID. The company operates two divisions internally with a staff of 22. The Metal Fabrication Division features quick turn-around prototype sheet metal and parts. They also have a division that performs SMT (surface-mount technology) stencil manufacturing. It utilizes laser-cutting systems built in-house by their metal fabrication team. All of this is contained in a 10,000 square foot facility at present. They are, however, breaking ground on a 23,000 square foot plant to be located in nearby Post Falls, just over the border from the state of Washington.

The principal officers are Mike and Karen Ray. Mike Ray is the President and CEO of IIT, Inc. He founded the company in 1982 after nearly a decade during which he ran his family's manufacturing company in Silicon Valley. He started his career while still in high school. Karen, who has a background in sales, has been working with Mike since their marriage in 1984.

Sharon Shepard (Director of Sales & Marketing) has held a variety of positions prior to joining the organization. She has a background in customer service working for companies that similarly offered quick-turn fabrication. When interviewed for this article, Sharon responded to our questions accordingly:

Marvin: Why was Coeur d'Alene selected? Tell us about the advantages of having a plant in this scenic location.
Sharon: Mike and Karen chose to locate in northern Idaho because of its business-friendly environment and the close access to international shipping routes. Since the nature of our business is quick-turn, they located next door to a FedEx hub and not more than 30 minutes from Spokane International airport. The new facility in Post Falls will bring us even closer to the airport by 12 minutes allowing us to provide an even quicker turnaround time.

M: How did you come to be associated with this firm?
S: I was born and raised here in north Idaho. I worked in a few other service-oriented positions prior to IIT, Inc., including a stint in physical therapy and bookkeeping. I joined IIT in July of 2000 as an assistant bookkeeper and soon turned to customer service and sales. By working closely with many contract manufacturers and original equipment manufacturers requiring same day and next day turnaround for SMT tooling, it made it easy for me to relate to the quick-turn requirements of our metal fabrication clients. I had always had a desire to work with the public, yet have freedom to try new things. IIT has been that opportunity and I am very proud to be a part of the company Mike and Karen have built.

M: Is there a newly developed product ready for release?
S: The very nature of prototype metal fabrication involves the creation of a client's ideas or future products in a quick and precise manner and usually in short runs, precluding the opportunity for in-house product development. Our SMT division, although very similar in this premise, has had the opportunity to create a limited number of products, such as our interchangeable stencil system (ProFrame®), that is widely used throughout the United States and worldwide.

M: Finally, one last word on the services offered by your organization.
S: At IIT, Inc., we provide the highest quality parts with the best possible customer service, along with quick-turn. We focus on meeting the customer's needs whether it be an SMT tooling with tolerances to .0001 that need to be delivered the next day to avoid a customer's line down; or a last minute request for one small bracket that allows a customer to show their new product at a trade show.

IIT's extensive design and engineering background is a tremendous advantage for customers requiring assistance with design for manufacturing. With our roots in the same-day SMT tooling industry, same-day sheet metal is easily accomplished also. A fully automated production environment allows us to successfully handle highest quality parts at incredible speeds. IIT also designs and manufactures AXIS® laser systems. This patented laser cutting system uses a sub .001 beam not currently available with other laser systems.

All of us here at IIT are grateful to *Nuts & Volts Magazine* for giving us the opportunity to tell our story. We welcome inquiries regarding our services. **NV**

Understanding Digital Buffer, Gate, and Logic IC Circuits

by Ray Marston

PART 4: NOR Gate, EX-OR, and EX-NOR Gate Circuits

This month, Ray Marston describes practical digital NOR gate, EX-OR gate, and EX-NOR gate logic ICs.

The first three installments of this five-part series explained modern TTL and CMOS logic gate basics and gave practical descriptions of some of the most popular digital buffer, inverter, AND gate, NAND gate, and OR gate digital ICs that are available. This month, we expand on this theme and describe a variety of popular NOR gate, EX-OR gate, and EX-NOR gate ICs that are available from either your local supplier or from specialist dealers.

Practical NOR-Gate Digital IC Circuits

The output of a digital NOR gate goes low when any of its inputs (A or B, etc.) go high. One easy way to make a NOR gate is to combine a basic diode OR gate with a transistor or IC inverter stage, as shown in the three-input NOR gate circuits of Figures 1(a) and 1(b). NOR gates of this type are reasonably fast and cost-effective and can easily be expanded to accept any desired number of inputs by simply adding one new diode for each new input.

Figure 2 lists basic details of the 10 most popular NOR gate ICs; of these, the 74LS02, 74HC02, 4001B, and the unbuffered 4011B (see Figures 3 and 4) are all Quad two-input types. The 4025B and the 74LS27 and 74HC27 (see Figures 5 and 6) are Triple three-input types, and the

Device	Type	Description
74LS02	LS TTL	Quad 2-input NOR gate
74HC02	CMOS	Quad 2-input NOR gate
4001B	CMOS	Quad 2-input NOR gate
4001UB	CMOS	Unbuffered Quad 2-input NOR gate
4002B	CMOS	Dual 4-input NOR gate
74LS260	LS TTL	Dual 5-input NOR gate
4025B	CMOS	Triple 3-input NOR gate
74LS27	LS TTL	Triple 3-input NOR gate
74HC27	CMOS	Triple 3-input NOR gate
4078B	CMOS	8-input NOR gate

FIGURE 2. Ten popular NOR gate ICs.

FIGURE 3. Functional diagram of the 74LS02 or 74HC02 Quad two-input NOR gate IC.

FIGURE 4. Functional diagram of the 4001B or 4001UB Quad two-input NOR gate IC.
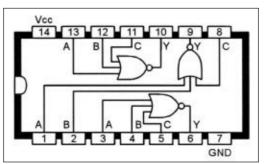
FIGURE 5. Functional diagram of the 4025B Triple three-input NOR gate IC.

FIGURE 6. Functional diagram of the 74LS27 or 74HC27 Triple three-input NOR gate IC.

FIGURE 7. Functional diagram of the 4002B Dual four-input NOR gate IC.

FIGURE 8. Functional diagram of the 74LS260 Dual five-input NOR gate IC.

FIGURE 9. Functional diagram of the 4078B Dual eight-input NOR gate IC.

4002B and 74LS260 (see Figures 7 and 8) are Dual four-input and five-input types, respectively. The 4078B (Figure 9) is an eight-input NOR gate IC.

When using NOR gate ICs, each unwanted gate should be disabled by shorting all of its inputs together and tying them to one of the IC's supply lines. In CMOS ICs, the shorted inputs can be wired directly to either supply line, but in TTL ICs the inputs must (to give minimum quiescent current consumption with good stability) be tied directly to the ground rail, as shown in Figure 10.

Sometimes when using NOR gate ICs, you may not want to use all of a gate's input terminals. In this case, the unwanted inputs are best disabled by shorting them directly to ground, as shown in the examples of Figure 11. A NOR gate can be made to act as a simple inverter by either shorting all of its inputs together or by grounding all but one of its inputs; note, however, that the fan-in of a TTL NOR gate is directly proportional to the number of inputs used, so the first method is thus (theoretically) the best, since it offers the lowest fan-in value, as shown in Figure 12.

NOR gates are fairly versatile devices. The effective number of inputs of a NOR gate can be increased by applying the extra inputs via a diode or IC OR gate, as shown in Figure 13. Figure 14 shows various ways of using two-input elements to make two-input or three-input OR gates or a three-input NOR gate. Note that a NOR gate can be converted into an AND gate by simply inverting all of its inputs. Figure 15 shows how three two-input NOR gates can be used to make a single AND gate.

FIGURE 10. Ways of disabling TTL NOR gates.
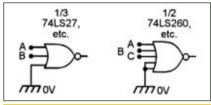
FIGURE 11. Basic ways of disabling unwanted TTL NOR gate inputs.
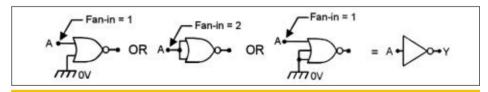
FIGURE 12. Ways of using a TTL NOR gate as a simple inverter.

Practical EX-OR and EX-NOR IC Circuits

The output of an EX-OR gate goes high
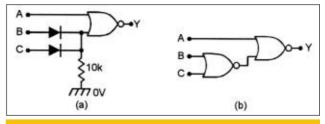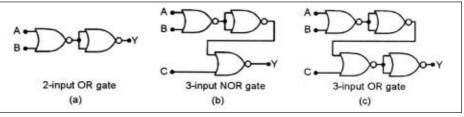
FIGURE 13. Ways of increasing the effective number of inputs of a NOR gate.

FIGURE 14. Ways of using two-input NOR gates to make various OR and NOR gates.
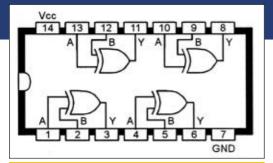
FIGURE 16. Functional diagram of the 74LS86 or 74HC86 Quad EX-OR gate IC.
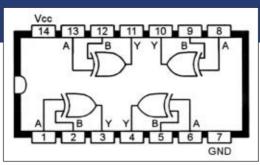
FIGURE 17. Functional diagram of the 4070B Quad EX-OR gate IC.
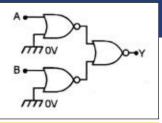
FIGURE 15. NOR gates used to make a two-input AND gate.

BEST METHOD   2nd BEST METHOD
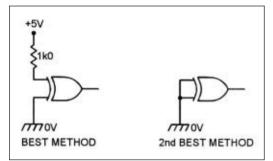
FIGURE 18. Two ways of disabling unwanted TTL EX-OR gates (see text).

BUFFER   INVERTER
(a)   (b)
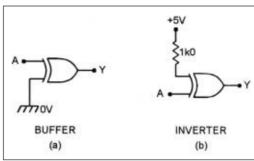
FIGURE 19. Ways of using TTL EX-OR gates as (a) buffers or (b) inverters.

FIGURE 20. An EX-NOR gate made from two TTL EX-OR gates.
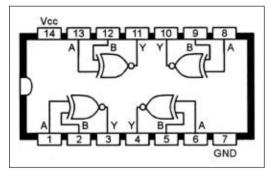
FIGURE 21. Functional diagram of the 4077B Quad EX-NOR gate IC.
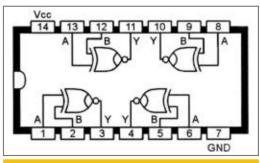
FIGURE 22. Functional diagram of the 74HC266 Quad EX-NOR gate IC with open-drain (o.d.) outputs.
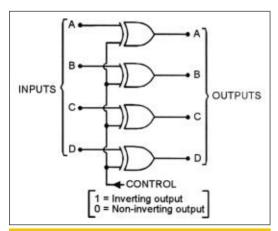
FIGURE 23. Four-bit True/Complement generator.
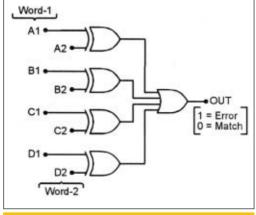
FIGURE 24. Four-bit logic state comparator.

only when its two inputs are at different logic levels. The most widely used EX-OR gate ICs are the 74LS86 TTL and the 74HC86 and 4070B CMOS Quad types (see Figures 16 and 17). If one or more of a CMOS EX-ORIC's gates are unwanted, it can be disabled by simply grounding both inputs. In the case of a

TTL EX-OR IC, unwanted gates are best disabled by grounding one input terminal and tying the other high via a 1K resistor, as shown in Figure 18, as this results in minimum quiescent current-consumption. Alternatively, if current drain is not impor-tant, both inputs can simply be tied to ground as shown.

EX-OR gates are quite versatile. An EX-OR gate can be made to act as a non-inverting buffer by simply grounding its unused input, as shown in Figure 19(a), or as an inverting buffer by tying the unused input high (via na 1K resistor in TTL types), as shown in Figure 19(b). Thus, two EX-OR gates can be used to make a single EX-NOR gate by connecting them as shown in Figure 20, where the right-hand gate is used to invert the output of the left-hand gate. Note that Quad EX-NOR CMOS ICs are also available in dedicated IC forms as the 4077B and the 74HC266 (see Figures 21 and 22), but that the latter IC's gates have open-drain outputs.

Figures 23 and 24 show two other useful EX-OR gate applications. In Figure 23, four EX-OR gates are fed

FIGURE 26. Binary half-adder circuit.

A	B	SUM	CARRY
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

with a common control signal that enables a four-bit 'ABCD' input code to be presented in the form of eithera true (direct) or complemented (inverted) ABCD output, thus making the four-bit True/Complement outputs available via five (rather than eight) terminals. The circuit in Figure 24 simply compares the logic states of the two four-bit words and gives a logic 0 output if the two words are identical, and a logic 1 output if they differ.

One of the most important applications of the EX-OR gate is as a binary adder. Figure 25 lists the basic rules of binary addition and Figure 26 shows how an EX-OR and an AND gate can be used to make a practical half-adder circuit that can add two binary inputs together and generate SUM and CARRY outputs. The circuit is called a half-adder because it can perform only a very primitive form of addition that does not enable it to accept a carry input from a previous addition stage.

A full-adder is a far more useful circuit that can accept a carry input, perform two-bit binary addition, and generate a carry output; such circuits are fully cascadable, enabling groups of circuits to perform binary addition on digital numbers of any desired bit width.

Figure 27 shows one way of building a two-bit full-adder circuit, using three EX-OR gates, two AND gates, and an OR gate. In practice, four-bit full-adders are readily available in the forms of the 74LS283 and 4008B ICs. **NV**

EDITOR'S NOTE
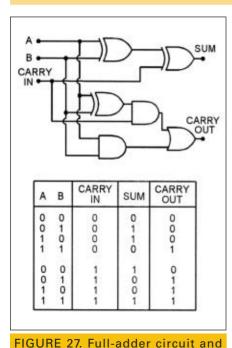
You may have noticed a different notation of resistor values in this article series. In Europe, the decimal point is replaced with the magnitude of the resistor value. So 2.2K becomes 2k2 and 3.3M is written 3M3. — *Ed.*

FIGURE 27. Full-adder circuit and truth table.

A	B	CARRY IN	SUM	CARRY OUT
0	0	0	0	0
0	1	0	1	0
1	0	0	1	0
1	1	0	0	1
0	0	1	1	0
0	1	1	0	1
1	0	1	0	1
1	1	1	1	1

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Introduction to
3D SCANNING

by Dan Mauch

Finally ... affordable 3D! Three dimensional (3D) scanning technologies have been around for several years but for most of us these have been unavailable. The very high costs and complexities involved have attributed to this. While there have been some low cost attempts that have been posted on the web, most have been fairly crude.

With what I am about to show you now, you will be able to make 3D scans at a fraction of the cost while achieving quality comparable to some of the high end products out there. This scanner can be used by graphic artists, gamers, reverse engineers and especially by those that have computer aided design (CAD) computer aided manufacturing (CAM) programs and equipment for rapid prototyping or 3D capable computer numerical control (CNC) machines. Best of all, this project involves nuts, volts, lasers, a video camera, and a computer!

Background

First, a little background. There are many types of 3D scanners but, basically, these can be categorized into "contact" and "non-contact" scanners. The contact types are straightforward in their design and use. These use a probe that contacts the object to be scanned. A computer program runs a mechanism that would move the probe (typically, a gimbal mounted switching device) back and forth over the object recording where the probe makes contact. At the end of the cycle, it produces what is a called a point cloud file. The file includes the locations of each contact point that was recorded. A single point cloud entry would look like this: X1.124, Y.097, Z -1.075. While they can be very precise, contact type scanners are also very slow, taking hours or days to scan an object.

Non-contact scanners come in many configurations. They are usually much faster, taking minutes and sometimes only seconds to scan an object. Optical non-contact 3D scanners are the most popular. They can be set up for topographical scanning that takes 3D images of an object in a frontal fashion for scanning a face, medallion, or coin, for instance. Another configuration is full object scanning that rotates the object 360 degrees and are called "circumference scanners" (3DCS).

These scan the rotating object, capturing most of the details in one session. The scans require minimal post processing, since it is not necessary to merge multiple scans. Optical non-contact 3D scanners typically involve the use of a laser to project a line over the object, a turn table to rotate the object, a camera to register the scan, and a computer with software to take the images from the camera and process them into a 3D model representation (see Figures 1 and 2). Many parameters need to be set to do this correctly. It may seem complicated at first, but once a few scans are made it becomes easier.

The scanner that this article will address is a 3D circumference scanner. It uses a Digital

Video (DV) camera such as a Sony™ Handycam™. However, any recent video camera, PAL (higher resolution), or NTSC will do. The camera should preferably have a remote control, FireWire (IEEE 1394) connector, image stabilization, and at least manual iris (exposure) and focus controls. You will need a tripod to support the camcorder. A precision turntable and a laser line module with support stand kit are available from Camtronics listed in the source box.

3D scanning typically involves some serious CPU processing and system memory allocation. The PC should run Windows XP and be equipped with a 2 GHz CPU and 2GB of RAM or more with a FireWire connection. The graphics card should be OpenGL compliant (no shared memory). The scanner also allows you to capture the colors of the object (textured scanning) using a halogen lamp. For the software, 3D Scan Triangles from Intricad, is available from Camtronics, as well.
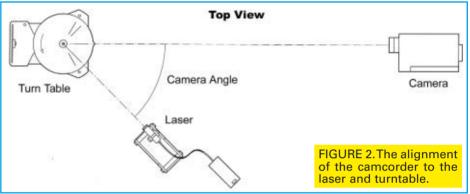
Process Overview

Setup and Calibration

As shown in Figure 2, the video camera is set up on a tripod nine feet from the center of the turntable. The turntable is turned on and its speed setting rotates one revolution in 45 seconds. The object is placed on the turntable and the camera is aligned horizontally and vertically with the object maximized in the camera's field-of-view. The laser line stand is located at a 45 degree angle to the centerline of the already leveled turntable and video camera. There are reference lines inscribed on the top of the turntable making the above alignments easy.
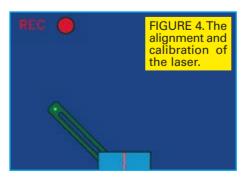
The turntable (Figure 3) consists of a stepper motor, a stepper motor driver with a built-in pulse generator to accurately turn the object, and a printed circuit board (PCB) that comprises the latch relay circuit and an LED. The LED on the turntable is adjusted so that it is not blocked from the camera's view by the object to be scanned. The LED switching will serve to indicate when the object has made a full turn. At the back of the turntable, there is a control panel with a pot for adjusting the motor speed, a power connector,

and two switches. One switch enables the stepper motor driver's output and the other is the directional control.

The object is temporarily removed and a small angle profile (serving as a calibrator) is placed exactly on the centerline of the turntable and facing the camera. The laser line module is turned on, focused, and rotated so the line is plumb and in-line with the reference marks on the turntable. The room lights are turned down to the lowest level (unstable or bright lighting would otherwise impair the scan process). The video camera then records a few seconds of this calibration procedure which is used later on to tell the software where the turn table centerline is (see Figure 4).

FIGURE 1. The 3D setup.

FIGURE 2. The alignment of the camcorder to the laser and turntable.

FIGURE 4. The alignment and calibration of the laser.

Scanning

Next, the object is replaced on the centerline of the turntable. The turntable is switched on and the camera is set to record. As the turntable rotates, a protuberance on the turntable contacts and engages a microswitch that turns on a latching circuit. This circuit keeps the LED

FIGURE 3. The turntable assembly.

FIGURE 5. The camcorder paused and the LED on.
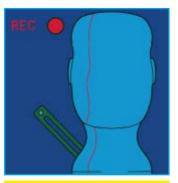
FIGURE 6. The camcorder recoding the laser line and the LED off.
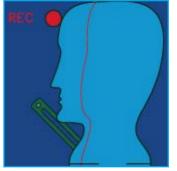
FIGURE 7. The object being recorded while rotating.
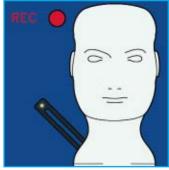
FIGURE 8. The recording completed and the LED on.

turned off until the turntable has rotated 360 degrees. After the object has been fully rotated, the microswitch is tripped again and the latch circuit turns the LED back on. If texture is required, the halogen lamp is switched on (laser is switched off) for another scan revolution pass and then the recording is stopped (see Figures 5-8).

Converting a Video Scan into a Raw Scan Data File

The video is now ready to be played back into the software called CScannerTAV1. First, you establish the FireWire connection. Then use the software to set up up your playback and to record it into the program and save it. After it is saved, the video is now an .avi file on your hard drive. Next, using the program controller, the vertical line of a slider is used to coincide with the previously recorded calibration line on the turntable. This tells the program where the center of rotation is. The recorded video of the scan is played and the program allows

you to go frame by frame through the video to locate the first frame (where the LED went off) and the last frame (LED switches back on again). This tells the program where to start and stop processing in order to get the exact 360 degree rotation of the object. The video is then auto processed by the program to produce a raw scan data (.rsd) file which is then stored on the computer.

Converting an .rsd File into a 3D Model

Now that we have scanned the object and created an .rsd file, we can now close the CscannerTAV1 program and load the BuilderTAV1 program also provided in the kit. Here we load the .rsd file that we recorded. This program optimizes the file, builds it, and then triangulates the thousands of data points into a 3D model (Figure 9). The object can then be viewed in the program as a surface or a wire frame (Figure 10) from any point (zoom, pan, rotate, tilt). Upon completion of using any of the filters to smooth the data, the file can then be converted to a non-loosely compressed

native file format or exported in one of six formats which are STL, RAW, VRML2, XYZ (cloud point), DXF, or OBJ.

While the above procedures seem complex, it becomes quite a bit easier as you go through the various steps a few times. The results, especially when texture is added, are impressive and sometimes almost lifelike. It also becomes clear that not all objects offer the same result. Some objects simply cannot be scanned and some objects — like glass — need to be painted or sprayed with white hair coloring in order to be scanned.

Hardware Overview

Detailed instructions on the assembly of the laser stand and the turntable are provided with the kit. The unit is supplied with a turntable and laser support stand kit and powered up using a 12 VDC regulated power supply. The assembly of the laser stand is quite simple. It consists of six plastic pieces that are secured together by screws. The laser is focus-adjustable. It is lightly clamped using a small bracket to hold it in place and yet still allow positioning. Switch on the laser and observe a nice bright line. Adjust the line focus at about 15 inches from a white piece of paper (this is the typical distance between laser and turntable).

WARNING! These laser modules emit radiation that can be harmful to the eye! Do not look directly into the laser aperture. Direct viewing of laser beams at close range may cause eye damage.

The turntable uses five plastic plates. The latching relay circuit

FIGURE 9. A scan of a tennis shoe that was processed in the Builder Program.
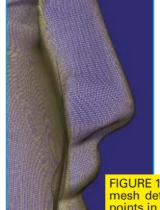
FIGURE 10. Wire frame mesh detailing all the points in the scan.

board is assembled using the instructions provided with the parts. It consists of only 10 components and six wires soldered to the PCB. The latching relay circuit board is mounted on the acrylic plastic top plate using the provided spacers. The stepper motor and microswitch are installed and the assembled stepper motor driver is prepared and installed on the bottom plate. The control plate switches, pot, and power connector are installed and wired. The stepper motor is then connected to the driver board, observing the color-coding of the wires to the outputs of the driver as shown in the instructions. When wiring is completed, the upper and lower pates are secured using plastic standoffs and screws. That's it!

One of the exciting applications of 3D technology is its use with rapid prototyping. Take a look at the website **www.fabathome.org** — they are doing some amazing work. From their website the following quote was taken that says it all:

"Inspired by this history, the goal of this project is to offer an open-source, low-cost, personal SFF (Small Form Factor) system kit, which we call Fab@Home. The aim of this project is to put SFF technology into the hands of those same curious, inventive, and entrepreneurial citizens. In addition, through this Wiki website, we hope to inspire users of Fab@Home to exchange their ideas for applications and their improvements to the hardware and software with us and each other. Several machines are already in use."

With the development of 3D scanning and the means to convert .stl files into parts using other technologies like the Fab@Home machine, I believe we are at the dawn of a new age in home and small business manufacturing of items that were unthinkable just a few years ago. **NV**

MAKING WAVES

by Gerard Fonte

Most digital circuits are limited to outputting zeros and ones. And while they can do this quickly and efficiently, there are many more types of signals in the real world that require something other than zeros and ones.

This article will briefly examine a number of methods of creating sine waves, and other waves, from digital values. The goal of this article is to familiarize the reader with a number of different techniques rather than to describe those techniques in detail.

Filtering a Square Wave

The simplest method of convert-

FIGURE 1. Basic four stage filter. The component values will vary according to the desired frequency. The frequency here is about 1,500 Hz.

ing a square wave to a sine wave is by filtering. Basically, a square wave consists of a fundamental frequency with a lot of higher harmonics. If the harmonics can be removed, then a sine wave of the fundamental frequency remains. This is easier said

PHOTO 1. A filtered square wave from Figure 1, output A. Not a very good sine wave.

than done because simple passive filters are not too efficient.

However, a reasonable sine wave can be created with a three-stage RC (resistor-capacitor) filter that is shown in Figure 1. Photos 1, 2, and 3 show the result of filtering a square wave at outputs A, B, and C, respectively. Photo 1 is the result of two stages of filtering (note different amplitude scale). It is certainly not a very good sine wave. Photo 2 looks more like a triangle wave than a sine wave. But it is certainly better than

PHOTO 2. The third stage (output B) is better, but still not a very good sine wave.

Photo 1. Photo 3 is actually a pretty good sine wave. The measured distortion is only a few percent. Not too bad for four resistors and four capacitors.

Note that the amplitude of the final filtered square wave is about 0.5 volts. This is only 10% of the original amplitude of 5.0 volts. It becomes clear that filtering with passive components reduces the amplitude.

Another problem with this approach is that it is frequency specific (about 1,500 Hz here). A higher input frequency will result in smaller final amplitude. A lower input frequency will not be filtered as well and will not be as good a sine wave. However, if all you need is a fixed frequency sine wave, this method can be very effective.

Active Filtering and Switched Capacitor Filters

You can certainly use active filters (filters incorporating an op-amp) to convert a square wave to a sine wave. They have the advantage of maintaining the amplitude of the signal but are fairly complicated and require a number of additional components. They are also limited to a fixed frequency response. This restricts their usefulness.

Switched capacitor filters are a form of an active filter. However, by switching capacitors on and off, the parameters of the filter can be modified by changing the switching rate. This makes the filter extremely useful for digital applications for a number of reasons. The first (already mentioned) is that the filter can be modified by changing the switching frequency. Another is that the switching signal is usually a digital clock with typical logic levels. This is easy to generate and control from a digital circuit.

There is also a direct relationship

PHOTO 3. After four stages, (output C) a pretty good sine wave is created. Distortion is only a few percent.

between the filter cutoff frequency and the clock/switching frequency. This is usually 50 or 100. What this means is that the clock frequency is generally exactly 50 or 100 times the cutoff frequency. (For example, for a filter with a cutoff frequency of 1 kHz, the clock would have to be 50 kHz or 100 kHz.) So, you can tune or sweep your filter over a wide range of frequencies very easily. The number of additional components needed to implement this approach can be very small (see Figure 2).

However, probably the strongest feature of these filters is that they can have extremely sharp cutoffs. This means that they can remove the higher harmonics of a square wave very effectively which leaves a pure sine wave. The "order" of the complete filter shown in Figure 1 is four. That is, with four capacitors it can reduce the higher frequencies at a rate that is four times a single capacitor (crudely speaking).

Figure 2 incorporates an eighth order filter, and filters up to the 10th order are available from Linear Technology. (Maxim is another manufacturer and National Semiconductor

PHOTO 4. A switched capacitor filter produces a stepped waveform because of the sampled nature of the circuit.
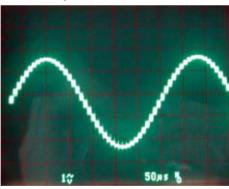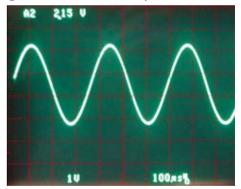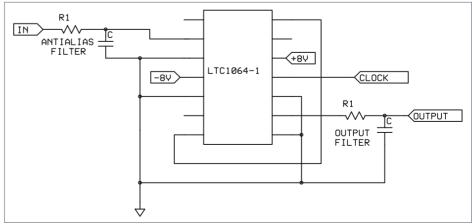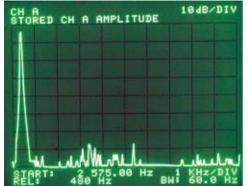
PHOTO 5. A simple RC filter after the switched capacitor filter creates a very good sine wave with very low distortion.

CH A
STORED CH A AMPLITUDE   10dB/DIV

START: 2,575.00 Hz   1 KHZ/DIV
REL: 480 Hz   BW: 60.0 Hz

marketed the first popular switched capacitor filter, the MF-10. This is still available for a couple of dollars.) The LTC1064-1 shown in Figure 2 has a frequency response that is about 72 dB down at 1.75 times the cutoff frequency.

If the cutoff frequency is set to 1,000 Hz, then a signal of 1,750 Hz will be reduced by 72 dB or to about 0.025%. This makes a very good sine wave out of a square wave. (Note that we've been discussing only low-pass filters. Switched capacitor filters can be any type of filter: low-pass, high-pass, band-pass, and notch.)

There are a couple of negatives to switched capacitor filters. Often they require a negative voltage for operation (in addition to a positive voltage). They can exhibit a DC offset in the output of up to a few tenths of a volt. Since they are in the class of "sampled circuits," they require an input anti-aliasing filter. However, this

is usually just a simple RC filter.

The output consists of a stepped waveform (see Photo 4). This can also be fixed with another simple RC filter. Photo 5 shows the final result of a square wave that is filtered with a seventh order switched capacitor filter. As you can see, it is a very nice sine wave. Photo 6 demonstrates this with the harmonics lost in the noise floor that is over 60 dB below the fundamental. This sine wave has less than 0.1% distortion.

Using a DAC

The traditional method of creating analog signals is by using a DAC (digital to analog converter). This takes a digital value (typically eight to 16 bits long) and converts it to an appropriate analog value. This approach also produces a stepped output signal and a simple RC filter can be used to remove the edges. With a 12 to 16 bit DAC, the output steps are so small that filtering is often not implemented.

You can make your own DAC for a few pennies. The basic circuit is shown in Figure 3 and consists of an "R-2R" ladder. With 1% resistors, you can go six to eight bits. With resistors matched to 0.1%, you can go 10 to 12 bits.

With a DAC, you can make any wave shape desired by outputting the proper value. Creating sine waves can be troublesome for small microcomputers because of the difficulty in creating the actual sine wave

FIGURE 3. The standard R-2R ladder network can convert a digital word into an analog signal. With precision resistor matching, up to 10 bits can be implemented.

values. It is not a simple mathematical operation. For that reason, a look-up table is often incorporated. Of course, a look-up table can be created for any desired wave shape. It is not limited to a sine wave.

This look-up table can be internal or external to the microcomputer and it can be RAM (random access memory) or ROM (read only memory). If it's ROM memory, the wave shape can't be changed. However, if it's RAM memory, the wave shape can be easily changed by simply modifying the contents of the memory. Using an external RAM to hold the wave shape is the typical situation for an instrument called an Arbitrary Waveform Generator.

Direct digital synthesis (DDS) is a method of generating precision sine waves with very accurate frequencies. It is an extension of the ROM look-up table described above. Over the last 10 years, DDS has become a very popular technique for frequency synthesis.

Pulse to Frequency Conversion

Many microcomputers today have internal counters that can be configured to automatically output a series of pulses in some form. These pulses can be modified either by duty cycle or by rate. Modifying the duty cycle is called PWM (pulse width modulation) and modifying the rate is called PRM (pulse rate modulation). Both of these methods can be used to create relatively low frequency signals (<1 kHz) fairly easily.

PWM is a very easy concept to understand. A square wave has a 50% duty cycle, so the average voltage over the whole cycle is 50% of the peak voltage. Likewise, a digital signal that is at logic one (or five volts) for 10% of the time will have an average voltage of one volt or 10% of the peak voltage.

Obviously, for this technique to work properly the PWM signal must

FIGURE 4. The PRM technique is easy to implement and can produce any output wave shape desired. It is limited to low frequencies. As shown, the upper frequency limit is less than 100 Hz.

be averaged. This is not a difficult task if the PWM signal is very high to begin with. A simple two or three-pole filter will average the signal quite well if the frequency of the modulating signal (desired wave form) is well below the PWM frequency. For example, if the PWM frequency is 20 kHz, then the modulation signal should be less than 0.1 kHz.
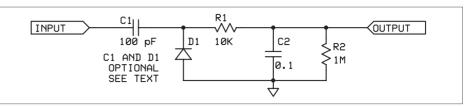
There are a number of trade-offs here. If you want a wide range of amplitude values, then the filter/averager will have to be better. Trying to average a signal that is on for 0.1% of the time without a bump in the output is not always a trivial matter.
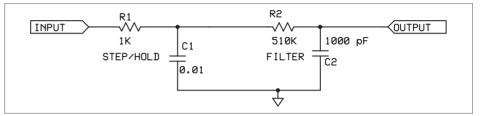
PRM is a technique that is somewhat similar. However, instead of changing the duty cycle, the number of pulses is changed. Typically, PRM incorporates a very short but fixed length pulse. The number of pulses averaged over a given period of time determines the voltage. Obviously, if there are five times as many pulses per second, the voltage will be five times greater. This approach again requires an output filter to average the pulses. This is also a type of frequency to voltage conversion.

Figure 4 is a typical circuit for PWM averaging. Capacitor C1 and diode D1 are used here to change a fairly long pulse — or an irregular one — into a very short pulse. The capacitor allows only the edges of the pulse to pass and the diode removes the negative-going pulse. If the output pulse is already very short, these components can be eliminated. Resistor R1 and

capacitor C2 form the averaging circuit. Resistor R2 is a bleeder resistor to allow a charge on C1 to dissipate. As shown, the upper frequency limit is under 100 Hz.

PWM has the useful characteristic of being able to act like a charge pump, as well. Depending on how the diode is connected, the output can be a negative voltage (reverse D1) or a voltage above the power supply (anode of D1 connected to Vcc).

Step-Hold

One technique that is rarely used but holds great flexibility is the step-hold method. This requires that the driving signal can be turned off (or three-stated). This is not a problem for modern CMOS microcomputers or ASICs (application specific integrated circuits). It is generally a trivial matter to turn any pin into an input which has a very high impedance (typically >10 megohms). In effect, this disconnects
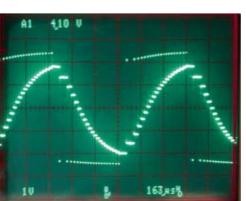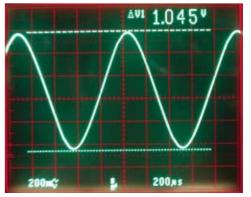
FIGURE 5. The simple step-hold approach looks like a two-pole filter but operates very differently. A small current is briefly applied to C1 via R1 to increase or decrease the voltage on C1. Then the driving signal is turned off and C1 holds the voltage. R2 and C2 filter out the step edges.

the output pin from the circuit. (Note: The step-hold and the PWM techniques are described in much more detail in the February '05 *Nuts & Volts* issue.)

The basic idea is to output a small pulse to put a charge on a capacitor and then disconnect the driving pin (three-state it) so that the capacitor will hold the value. The output will result in a stepped waveform of any desired shape. This is then filtered to remove the steps with a simple RC filter. Figure 5 shows how this is done. (While the circuit looks like a two pole filter, its

PHOTO 8. After filtering the step-hold wave, the result is a pretty good sine wave.

PHOTO 7. The step-hold signal measured at the output pin of the microcomputer (Figure 5). The small pulses pull the voltage on the hold capacitor up and down. The horizontal steps are where the pin is three-stated and show the voltage held on the capacitor.

operation is very different.) Resistor R1 acts as a current limiting resistor so that the capacitor (C1) doesn't charge all the way immediately. Changing R1 changes the step size. The filter is comprised of R2 and C2.

This approach has a number of useful features. The first is that it can be very fast. The maximum frequency is limited by the number of steps you choose and the speed of the microcomputer. If you use a 40 MHz computer chip with 40 steps per wave, you can probably get up to 10,000 Hz for an output signal with tight code.

Additionally, hardware is simple and any waveform shape can be created. Photo 7 is the wave shape taken at the output pin. The stepped wave is created by the very small pulses near Vcc and ground pulling the signal up and down. The filtered 1,000 Hz sine wave is shown in Photo 8. Considering the starting wave shape, this is pretty good.

A problem with this approach is that the size of the steps depends upon the present voltage on the hold capacitor. That is, the steps are not linear. This makes sense when you think about it. A capacitor does not charge in a linear fashion. The rate of voltage increase is less as the charge approaches the charging voltage. A larger current limiting resistor will make the steps more linear but the amplitude of the waveform will be smaller because the steps will be smaller, as well.

However, it is possible to use two different current limiting resistors for the same hold capacitor/filter by using two different outputs. Drive one pin/resistor for big steps and drive the other pin/resistor for small steps. This simplifies the control of the signal.

This approach can also be used for changing the filter capacitors on the fly. Instead of grounding the capacitors, connect them to an output pin. To enable that capacitor, drive the output low (to ground). To disable the capacitor, three-state the pin (make it an input). Considerable variations in filtering (or other circuits) can be accomplished with this technique.

Summary

There are a number of methods for making sine waves and other analog signals from digital values. Some are simple, some are more complicated, some have very limited applications, and others have a wide variety of uses. Having a number of options for your particular application can provide for a better solution. **NV**

PERSONAL ROBOTICS

UNDERSTANDING, DESIGNING & CONSTRUCTING ROBOTS & ROBOTIC SYSTEMS

■ GUEST HOSTED BY PETE SMITH

COMBAT ROBOTS RETURN TO NORTH CAROLINA

A FEW YEARS AGO, NORTH CAROLINA WAS ONE OF THE BEST places to live if you were interested in combat robotics. There were two major events held each year in the state. The North Carolina Robotic Street Fight was held each winter in Salisbury and the South East Combat Robotics organization (www.secr.org) held their big annual competition each year as part of the "Applefest" celebrations in Hendersonville.

That all ended in 2003. The main driving force behind the NCRSF — Chris Hannold — decided to stop running the event mainly due to the huge effort building up and dismantling the arena each time, and no permanent home could be found for it. There was one last event over the 4th of July weekend — and it was gone.

The SECR event was held in a large marquee erected on a playing field. The weather was hot even by North Carolina standards, and then the sky opened and dropped several inches of rain, flooding both the arena and the pits. Heroic efforts by the organizers allowed the event to be completed but they simply had enough of the outdoors. The search for a suitable venue in NC failed, so the event first moved to Alabama and finally to New Orleans, LA just before the Katrina disaster.

This sorry state of affairs left builders in NC no choice but to travel much farther to events if they wanted to keep competing. Luckily, someone had the dream of bringing a major event back.

Chuck Butler of Kernersville, NC bought the big 32 ft x 32 ft NCRSF arena from Chris and started looking for somewhere to be able to hold an event. In 2006, he finally found the ideal location in a corner

of the Bennett Uniform Manufacturing, Inc., warehouse in nearby Greensboro. This modern building had good ventilation for the summer, heating for possible winter events, and finally, plenty of space for the arena, audience, and pits.

In early January 2007, he sent out an email to all local builders that he was going to hold an event on the weekend of May 5th for bots right up to the superheavyweights and appealed for help in getting the arena ready.

I attended the first work party and it quickly became apparent to me that Chuck may have bitten off a little more than he could chew. The arena that had been adequate for heavyweights back in 2003 would not be safe for the vastly more powerful bots of today. We all sat down and discussed what we could do and still meet the May event

deadline. The main problems were the small section of the steel used on the supporting walls and the massive 32 foot span required for a roof.

The first problem could be solved by reducing the bot size allowed to Middleweights (120 lbs). Chuck already had a large number of 16 ft wooden joists which would make it easy to roof a 16 foot wide arena. An examination of the floor and walls revealed that it would be relatively simple to convert it to a modular arena that would be 16 feet wide and between 16 feet and 32 feet long, depending on the number of modules used.

The change in arena size and the announcement of a competition a couple of weeks later in California with large cash prizes dramatically dropped the numbers of bots that had

■ FIGURE 1

■ FIGURE 2

■ FIGURE 3

■ FIGURE 4

■ FIGURE 5

■ FIGURE 6

signed up to enter, so it was decided to run the event on just the Saturday rather than the full weekend.

Chuck, his son Jeremy, and other members of his family — plus some help from local teams — got the arena moved to the Bennett warehouse (Figure 1) and Chuck and Jeremy spent most of the final week assembling it and getting everything else ready.

Saturday dawned gray and damp, but the venue was a hive of activity when the competitors started arriving. The

■ FIGURE 7

arena (Figure 2) was a full 32 feet wide with 1/2" Lexan all around. The floor was 1/4" steel and very flat with smooth seams. Railroad ties were used around the periphery to keep the bots away from easy contact with the expensive Lexan.

Two local colleges — Central Carolina Community College (**www.cccc.edu**) and Guildford Technical Community College (**www.gtcc.edu**) — had built 80 lb. robots as part of their engineering programs and these competed in a separate set of obstacle, tug of war, sumo, and finally conventional fights.

There were not really enough fighting bots for a full competition, but the fights were arranged as a series of demonstrations of what the smaller bots can do. Fight announcing and commentary was very ably handled by WFMY News Channel 2 anchorman, Kent Bates.

Central Carolina's bot (Figure 3) took an early lead in the college competition when its more compact design layout made it easier to control and get around the obstacle course (Figure 4). Guildford's machine (Figure 5) was wider and, while it had plenty of power and speed, it was much tougher to drive. The ramp proved especially difficult to negotiate.

It was a similar story in the other

challenges, with Central always having just an edge over their opponent. Guildford had their best chance in the actual fight where it had extra flails added and then spun high speed as a classic thwack bot. They seemed to be winning until the bot lost one, then the other flail, and then stopped moving completely with signal problems. Central emerged as the clear overall winners.
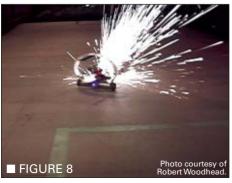
In the 60 lb. robot, "Crocbot" (Figure 6) with a beautifully painted shell and drumbot "Pnuisance" fought it out with Crocbot winning despite a lot of problems getting stuck under the railroad ties.

The Blade Spinners, "Totally Offensive" (30 lb.), "Surgical Strike" (12 lb.), and "Pure Dead Brilliant" (3 lb.) proved very popular with the crowd while fighting Armored Wedges "Xhilarating ImpaX (Figure 7) "CheepShot 3.0", and thwack bot "Longthread" (30 lb., 12 lb., and 3 lb., respectively).

"Totally Offensive," "CheepShot 3.0" and "Pure Dead Brilliant" came out winners of their classes. "Surgical Strike" can be seen delivering a big hit in Figure 8.

A couple of Ants fought it out in the Ant arena (Figure 9) with "Unithorn" taking first place.

"Totally Offensive" and "Pure

■ FIGURE 8
Photo courtesy of Robert Woodhead.

■ FIGURE 9

■ FIGURE 10

Dead Brilliant" also entertained the crowd with some smashing up of old printers and R/C cars.

Some kids from the audience got a chance to fight a couple of 12 lb. wedges supplied by Kitbots (**www.kitbots.com**). Hopefully, they will be back next time with their own bots!

The NCCCS (North Carolina Community College System) Cup was presented to Central Carolina Community College by Kent Bates (Figure 10) and the event was brought to a close.

Thanks to Chuck Butler, his family, and friends who made it possible to bring robot fighting back to North Carolina. Thanks also to Ray Bennett — owner of Bennett Uniforms (**www.bennettuniform.com**) — for the use of their excellent venue.

Plans are now being made to reinforce the arena to allow the heavier bots to compete safely and for a much bigger second event later in the year. Keep an eye on **www.carolinacombat.com** for details. **NV**

■ BY PETER BEST

DATACOMM LIKE A BIGSHOT

IF YOU WANT TO MONITOR AND CONTROL DEVICES via the Internet using a microcontroller, Ethernet is the packet transport of choice. Before folks like you and I cracked the code of the commercial Ethernet ICs and applied that technology to a microcontroller, we all had to learn to deal with SLIP (Serial Line Internet Protocol), the first protocol for transferring packets using a serial link over dial-up lines, or PPP (Point-to-Point Protocol), the more elegant dial-up protocol alternative to SLIP. Once you got all of that under control, you dealt with coding for a modem.

JUST CODE IT

Some pretty smart folks at iReady (the "i" stands for Internet) and Seiko saw the need to clear the fog surrounding SLIP and PPP and open up these protocols to those of the microcontroller persuasion. Seiko and iReady teamed up and produced a really useful IC — the S-7600A — which automated the tasks associated with speaking PPP from the mouth of a microcontroller. All of the software complication of PPP was crammed into a very small piece of silicon. The inclusion of PPP rules and regulations in the S-7600A hardware eliminated the need for the designer to write code for every nuance of a PPP session.

As of this writing, you can still access the iReady site (**www.iready.org**) and peruse the S-7600A applications. S-7600A applications of the day were based on the AVR 8051 variant and the then newly announced Flash-based Microchip PIC16F877. Although the S-7600A is no longer available through normal distribution channels, you can still get your hands on an S-7600A IC by logging on to the nChip website (**www.nchip.com**).

On the commercial development board side, Rabbit Semiconductor picked up the PPP ball and produced a really nice PPP software module to complement the Rabbit microprocessor and their Dynamic C development environment. You can still purchase the Rabbit PPP module today. The current availability of PPP code is a good thing as a designer of microcontroller based, long-distance Ethernet/Internet control applications can't count on having the convenience of a broadband connection at every remote site he or she has to service.

HELLO, BROADBAND

Users of dial-up connections gave up their trusty high-speed 56K modems and began to migrate to readily available routers and switches as broadband moved into the consumer marketplace. Despite the advances in Internet communications technology (as far as the newly anointed Internet gadget designers were concerned), the microcontroller was still a necessary item when it came to communicating with Internet-ready control and monitoring hardware using the newly available switching and routing equipment. However, microcontroller-based control-over-Ethernet designs aimed at exploiting the broadband and ultimately the Internet, included some new ICs with names like CS8900A and RTL8019AS.

Many other manufacturers followed suit with their own flavors of Ethernet engine ICs but the Cirrus Logic CS8900A and Realtek RTL8019AS caught on in larger numbers among experimenters and hobbyists. Fact is, the CS8900A and RTL8019AS were also in great demand as Ethernet engines in set-top boxes and cheap PC Ethernet add-on cards.

Because of their fine-pitch packaging, early Ethernet experimenters without the skill or tools to mount and solder CS8900A and RTL8019AS parts manually wired PC Ethernet add-on cards loaded with the designer's desired Ethernet engine IC into their microcontroller-based circuits. Seeing the need to provide a ready-made platform for the solder challenged, companies like EDTP Electronics, Rabbit Semiconductor, and Microchip offered up RTL8019AS development kits and boards.

NEARLY PERFECT, ALMOST

Although the RTL8019AS and CS8900A produce near perfect Ethernet devices when coupled with a

microcontroller, there are some drawbacks associated with using RTL8019AS and CS8900A parts in a microcontroller-based Ethernet design. If your microcontroller is to run at any other frequency than 20 MHz, then you must supply a pair of clocks; one for the microcontroller and a separate 20 MHz clock for the Ethernet IC. Both the RTL8019AS and CS8900A require a 20 MHz clock.

I've had many a nose-to-nose conversation with Ethernet boards generated from the bench at EDTP Electronics. EDTP Electronics offered a variety of Ethernet devices based on the RTL8019AS and the CS8900A. However, these are no longer available. You can still purchase the printed circuit boards (PCBs) for these devices from the folks at NERDVILLA (**www.nerdvilla.com**).

All of the EDTP Electronics Ethernet devices that included a microcontroller were based on Microchip PIC and Atmel AVR microcontrollers packaged in 40-pin DIP configurations. As long as the customer's final I/O requirements were small, the CS8900A/RTL8019AS-based EDTP Ethernet devices worked very well as network controllers or network nodes. The EDTP Ethernet platforms based on the RTL8019AS and CS8900A also worked very well as smart Internet devices.

The RTL8019AS requires five address lines, eight data lines, and six control lines. That totals to 19 I/O lines from the supporting microcontroller's I/O pool. If the Ethernet node design didn't require any other communications method (I^2C, RS-232, or SPI), 12 I/O lines scattered about from the various I/O ports of a PIC16F877 or PIC18F452 could be pulled into service. Ultimately, a 74HCT573 latch was incorporated into the EDTP RTL8019AS and CS8900A designs to add eight bits of output tapped from the microcontroller I/O dedicated to servicing the Ethernet IC's data bus.

Adding the 74HCT573 latch and an RS-232 port to the EDTP Electronics boards sucked up one more I/O pin for the LE (Latch Enable) pin of the 74HCT573 and a pair of pins (TX and RX) for the RS-232 port,

bringing the total available I/O to nine lines on a PIC16F877 or PIC18F452.

Subtract two more I/O lines if SPI or I^2C was a necessary part of the Ethernet node design. The point I'm trying to make here is that if your RTL8019AS or CS8900A Ethernet node design is heavy on I/O requirements, you will need to incorporate a high I/O pin count microcontroller into the design mix.

A BETTER WAY

Somewhere in Arizona a light bulb moment spawned the creation of the Microchip ENC28J60. With the announcement of the ENC28J60, microcontrollers with small I/O pools could be used in serious Ethernet node designs. The ENC28J60 lifted the Ethernet engine I/O requirements for address, data, and control lines by interfacing to the host microcontroller using SPI — a two-wire communications protocol.

Today, it is possible to Ethernet enable almost any microcontroller using the ENC28J60. Although SPI is a great improvement over the I/O and control mechanisms required by the RTL8019AS and CS8900A, SPI is the weak link of an ENC28J60-based Ethernet controller.

THE BEST WAY

What if we could get rid of the high I/O requirements, the separate clocks, and the SPI interface? To accomplish this, we would have to house the Ethernet engine, the clocks, and the SPI interface on the same piece of silicon as the microcontroller. However, the SPI interface has to go no matter what. Enter the PIC18F67J60.

The PIC18F67J60 is a 64-pin microcontroller that includes the ENC28J60 Ethernet engine and an integral Ethernet/microcontroller clock system. Datasheet to datasheet, the PIC18F67J60 is really a PIC18F6722 minus a few I/O pins, which were pressed into service as dedicated Ethernet interface pins on the PIC18F67J60. The PIC18F67J60 has provisions that use a single crystal to internally generate both the Ethernet engine clock and the microcontroller clock. Even with the theft of a few I/O lines to accommodate the Ethernet engine, the PIC18F67J60 retains 39 of the PIC18F6722's original 54 free I/O pins. PIC18F6722 dual-purpose I/O pins that provide I^2C, SPI, and RS-232 services were retained on the PIC18F67J60.

The SPI interface between the PIC18F67J60's internal Ethernet engine and the internal PIC microcontroller does not exist and has been replaced by a single microcontroller register, which allows data to flow at microcontroller processing speed between the PIC18F67J60's Ethernet engine and the PIC18F67J60's microcontroller.

Now that we have a single IC that incorporates a PIC microcontroller and a 10 Mbps Ethernet engine, what are we going to do with it? As you can see in Photo 1, the folks at EDTP Electronics don't miss much when it comes to embedded Ethernet devices. So, let's build up one of their new Ethernet MINI boards, which just happens to be based on the PIC18F67J60.

TOOLING UP

Thru-hole construction is far from dead. However, designing and build-

■ PHOTO 1. By the time you finish reading this month's Design Cycle, this is what we intend to end up with. This is the EDTP Electronics Ethernet MINI, a selfcontained 10 Mbps Ethernet node. The heart of the Ethernet MINI is a Microchip PIC18F67J60, which (under the covers) is an Ethernet-enabled PIC microcontroller.

ing with SMT (surface mount technology) components is the way to go. Surface mount components are more compact and take much less time to mount and solder than their thru-hole counterparts. In some situations, surface mount components exhibit superior electrical characteristics as compared to what a thru-hole component would offer in the same situation.

To support the previous statement, the Microchip PIC18F67J60 datasheet recommends that the PIC18F67J60 Ethernet engine bias resistor, which is attached between the PIC18F67J60's RBIAS pin and ground, be a surface mount device. And — by the way — the PIC18F67J60 only comes in a surface mount TQFP form factor.

I'm sure that many of you have

your own way of working with surface mount components. I do too ... I cheat. Instead of attempting to adapt everyday general-purpose soldering tools to SMT work, I use soldering equipment that is designed specifically for manually fabricating SMT-based circuitry.
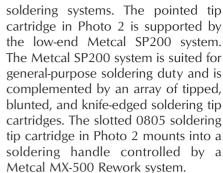
The soldering tip cartridges I will use to construct our Ethernet MINI are shown in Photo 2. Note that I said "tip cartridges" instead of soldering iron tips. The soldering tip cartridges in Photo 2 mate with soldering iron systems manufactured by Metcal, which is now a part of OKI. The typical Metcal soldering station consists of a soldering iron controller, a soldering handle, and a soldering tip cartridge, which fits into the soldering handle.

The soldering cartridge technology used by Metcal enables the soldering tip cartridge to heat to soldering temperature instantly. Once up to soldering temperature, the soldering iron controller maintains a constant temperature at the soldering point throughout the soldering cycle. The pointed soldering tip cartridge you see in Photo 2 has a tip that is fine enough to fit between the pins of a PIC18F67J60 device. The slotted soldering cartridge permits the soldering of an 0805-sized component with one soldering pass as the 0805 component can fit end-to-end within the slot jaws of the soldering cartridge.

My soldering station consists of a pair of Metcal

soldering systems. The pointed tip cartridge in Photo 2 is supported by the low-end Metcal SP200 system. The Metcal SP200 system is suited for general-purpose soldering duty and is complemented by an array of tipped, blunted, and knife-edged soldering tip cartridges. The slotted 0805 soldering tip cartridge in Photo 2 mounts into a soldering handle controlled by a Metcal MX-500 Rework system.
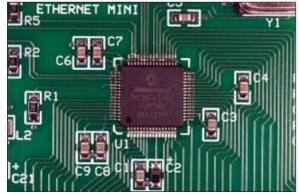
Like the SP200, the MX-500 Rework station consists of a soldering iron controller, a soldering handle, and a soldering tip cartridge. The Metcal MX-500 rework station is designed to accept specialty rework soldering tip cartridges such as the slotted 0805 soldering tip cartridge you see in Photo 2. My MX-500 soldering station also includes slotted soldering tip cartridges for 0603 and 1206 SMT parts.

In addition to slotted soldering tip cartridges, my Metcal MX-500 soldering tip cartridge collection includes SMT DIP (Dual Inline Package) soldering tip cartridges, which are most useful in removing SMT ICs in the DIP form factor.

Having the Metcal soldering tools makes easy work of assembling our Ethernet MINI. However, you can assemble the EDTP Electronics Ethernet MINI without the help of specialized soldering tools like those mentioned. Just get your hands on a fine soldering tip.

No matter which soldering tools you decide to use, you'll need to obtain some high-quality soldering flux. The solder plating on the EDTP MINI PCB supplies a sufficient amount of solder to the PIC18F67J60 pins when the solder pads are coated with a good liquid solder flux.

I apply solder paste to the 0805 component pads. The solder paste not only adds that extra bit of needed solder for the larger soldering area, the viscosity of the solder paste also holds the component in place. Regardless of the soldering technique you choose, the idea is to establish a good electrical connection without damaging the surface mount components. Align the PIC18F67J60 and ST3232 on their solder pads and tack down the corner pins to hold the parts
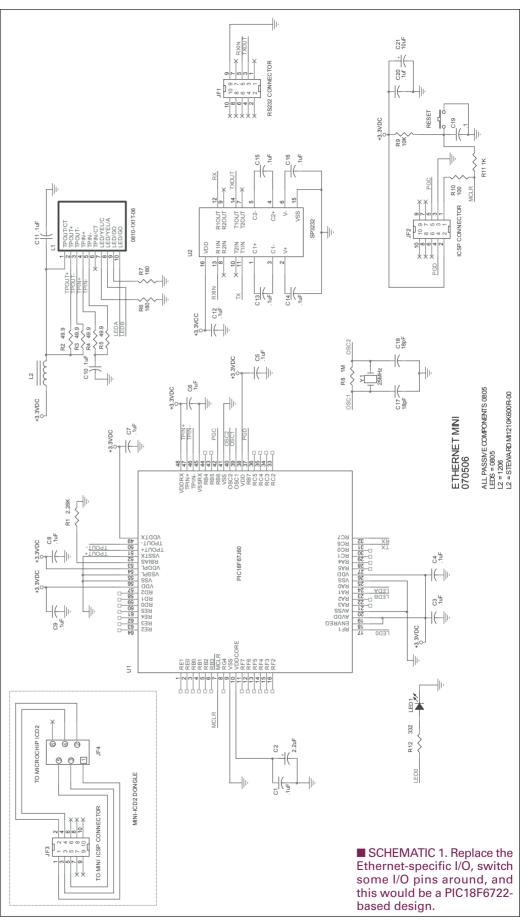
in place for fluxing and final soldering. Be patient while working with the SMT parts and you will be successful. With that, let's get on with assembling Ethernet MINI.

PARTS AND PIECES
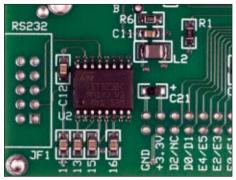
The EDTP Ethernet MINI has a minimum of parts to mount and is very easy to assemble. The very first part you should mount and solder is the PIC18F67J60 (U1). If you feel that you don't have the skills or tools needed to solder the PIC18F67J60 into place, EDTP Electronics offers an Ethernet MINI PCB with the PIC18F67J60 mounted and soldered. Purchasing an EDTP MINI PCB with a factory mounted PIC18F67J60 enables you to assemble the remainder of the Ethernet MINI using a general-purpose soldering iron. The PIC18F67J60 you see in Photo 3 was manually mounted and soldered using the pointy soldering cartridge shown in Photo 2.

Once you have mounted and soldered in the PIC18F67J60, it is a good time to solder in U2, the ST3232. The ST3232 is used to interface the PIC 18F67J60's EUSART logic level voltages to the positive and negative voltage swings found on a regulation RS-232 interface. The ST3232 leads are relatively large and are easy to tack down and solder. So, you shouldn't have any trouble in putting the ST3232 down on the MINI PCB.

While we are in the ST3232 neighborhood, let's go ahead and mount C12, the 0.1 µF power supply bypass capacitor, and the

■ SCHEMATIC 1. Replace the Ethernet-specific I/O, switch some I/O pins around, and this would be a PIC18F6722-based design.
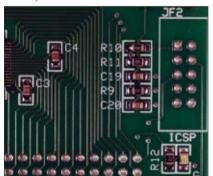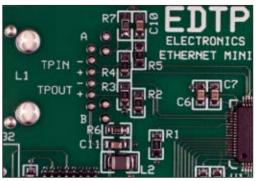
■ PHOTO 4. Nothing to it! You'll only make things hard by mounting JF1 before you place and solder in the ST3232 and all of its supporting passive components. Take care when you mount C21.

ST3232 charge pump capacitors C13-C16, which are also non-polarized 0.1 µF capacitors. When you are finished with the ST3232 supporting components, this would also be a good time to place and solder in C21. C21 is a 10 µF tantalum that is intended to help suppress any spurious noise that may originate from your +3.3 VDC external power source. Note that C21 is polarized. So, mount C21 as shown in Photo 4.

The next components you should install are the PIC18F67J60's 0.1 µF power supply bypass capacitors C3-C9. The power supply bypass capacitors are not polarized. If you check the Ethernet MINI schematic (Schematic 1) you will see that the ENVREG pin is tied to +3.3 VDC enabling the PIC18F67J60's internal 2.5V regulator. The resulting +2.5V is used to

■ PHOTO 6. In my case, this circuitry interfaces the EDTP Electronics MINI to a Microchip MPLAB ICD2 programmer/debugger. The MPLAB ICD2 interface is completed with the addition of the Ethernet MINI dongle, which plugs into JF2 and converts the 10-pin header to a six-pin RJ-12 interface.

power the PIC18F67J60's core. Filter capacitors C1 and C2 provide stability for the core voltage regulator. As you can see in Photo 3, you should pay particular attention to mounting and soldering C2 as it is a 2.2 µF polarized tantalum capacitor.

Take another look at Photo 3. Swing out to the left of the PIC18F67J60 and locate precision resistor R1. R1 is a 2.26K, 1% precision resistor that influences the signal amplitude of the TPOUT pin pair. Microchip recommends that this resistor be mounted in such a way as to not capacitively couple with adjacent pins or traces that may inject noise into the PIC18F67J60's RBIAS pin. As you can see, I've put R1 out in left field per Microchip's recommendations. Go ahead and solder R1 onto the Ethernet MINI PCB at this point.

Photo 5 is a bird's-eye view of the PIC18F67J60's Ethernet interface passive components. Precision resistors R2-R5 in conjunction with capacitor C10 (0.1 µF) are used to properly terminate the PIC18F67J60's transmit and receive interfaces. A pair of 49.9Ω 1% resistors lies across each of the PIC18F67J60's transmit and receive interface pairs. A 0.1 µF power supply bypass capacitor (C11) works with L2, a high-current ferrite bead, to

■ PHOTO 5. Don't mount the pulse transformers before soldering in all of the passive components that complement it. Yes "transformers." There is actually a pair of pulse transformers inside the MagJack can.

suppress power supply noise.

Mount R2-R5, C10-C11, L2, and the 180Ω LED current limiting resistors R6 and R7 at this time. Note that the Ethernet indicator LEDs are optional and the PIC18F67J60 pins that drive the LEDs can be used as standard microcontroller I/O instead, if you desire.

Let's jump to the opposite end of the Ethernet MINI PCB and work on the reset and programming/debugging circuitry. Programming voltage is supplied to the PIC18F67J60's MCLR pin via pin 1 of the ICSP connector JF2. R10, a 100Ω resistor, functions as an isolation device that helps prevent programming voltage overshoot at the MCLR pin. R9, a 10K resistor, and C19, a 0.1 µF non-polarized capacitor, make up the RC circuit that is used to reset the PIC18F67J60 upon power up.

Depressing the RESET button discharges C19 and takes the PIC18F67J60 MCLR pin to a logical low level to bring about a user initiated reset. To isolate the RC reset circuit from the high voltage generated during programming, we must add R11, a 1K resistor, between the MCLR pin and the RC reset circuitry. C20, another non-polarized 0.1 µF capacitor, acts in the power supply bypass role at the programmer/debugger power point. Now that you know what the reset and programming/debugging components do, mount them up and solder them in as shown in Photo 6. Resistor R8 (1M) and 18 pF capacitors C17 and C18 are all that Y1, the 25 MHz crystal, requires to complete the PIC18F67J60's

■ PHOTO 7. The PIC18F67J60's Ethernet engine needs the 25 MHz clock. We take the 25 MHz and use the PIC18F67J60's PLL to supply a 41.6667 MHz clock signal to the PIC microcontroller portion of the PIC18F67J60.
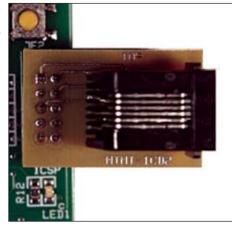
■ PHOTO 8. If you use Microchip programmers and debuggers, you can simply plug the programmer/debugger into this interface and go to work.

internal clock oscillator circuit. There's nothing new or scientifically significant here. So, mount 'em up and solder 'em down just as they are shown in Photo 7. If you haven't already done so, go ahead and put the RESET switch into place and solder it down.

Take another look at Photo 6. A resistor and LED mount just below the JF2 pads. If you trace the connections of the LED and its current limiting resistor using the schematic, you will find them fed by the PIC18F67J60's RF1 I/O pin. The 332Ω current limiting resistor (R12) and LED1 are optional components that I use to display a heartbeat when the Ethernet MINI driver code is running. You can use them for anything you like if you mount them and solder them in.

That covers the mounting and soldering of all of the Ethernet MINI's surface mount components. Recheck your work before installing the MagJack and 10-pin male headers. It is important to make sure that the key notch of each of the 10-pin male headers is on the inside of the board as this will correctly align pin 1 of each of the 10-pin male headers. There is also a pin 1 marker on each 10-pin male header that can be used to align pin 1 of the 10-pin male header to the

square pads (pin 1) of JF1 and JF2.

Before you can load up the PIC18F67J60 with some driver code, you'll need a way to interface to a PIC programmer capable of programming the PIC18F67J60. The Ethernet MINI's programming interface is regulation Microchip and follows the rules set forth by the ICSP documentation. EDTP Electronics offers an ICSP adapter, affectionately known as the Ethernet MINI dongle that plugs directly into the ICSP port (JF2). The Ethernet MINI dongle adapts the Ethernet MINI's 10-pin ICSP arrangement to the standard Microchip six-pin RJ-12 configuration. Photo 8 pretty much tells the story. The six-pin RJ-12 jack mounts on the top of the Ethernet MINI dongle PCB and the 10-pin female header mounts on the bottom layer of the dongle PCB. The

SOURCES

■ *EDTP Electronics, Inc.* (**www.edtp.com**) — Ethernet MINI

■ *HI-TECH* (**www.htsoft.com**) — HI-TECH PICC-18 C compiler

■ *microEngineering Labs* (**www.melabs.com**) — PICBasic Pro

■ *OKI* (**www.okinternational.com**) — Metcal SP200; Metcal MX-500

■ *Microchip* (**www.microchip.com**) — PIC18F67J60; ENC28J60; MPLAB ICD2; MPLAB IDE

Ethernet MINI dongle PCB sides are clearly marked TOP and BOTTOM.

TAKE A TEST DRIVE

I've provided a set of drivers for the Ethernet MINI that you can download from the *Nuts & Volts* website at **www.nutsvolts.com** The drivers you can get right now were written using the HI-TECH PICC-18 C compiler. Next time, I'll show you how to translate those lines of Ethernet MINI C source into microEngineering Labs PICBasic Pro source code. **NV**

CONTACT THE AUTHOR

■ *Peter Best can be reached via email at peter@nerdvilla.com.*

■ BY CHUCK HELLEBUYCK

HOT WHEELS DRAG RACE FINISH GATE

ON A RECENT TRIP TO THE LOCAL KMART, I saw that Mattel had released a series of classic Hot Wheels sets similar to the ones you could buy when I was a kid. I bought one of the two-lane drag race types, with the mechanical flag that flipped one way or the other to indicate which car got to the finish line first. It was the classic drag race toy from my youth. My daughter was fascinated with it, but had a hard time resetting the flag. It would stick sometimes and not indicate any winner. I decided this was a good time to replace mechanical with electronic, and I chose Basic Micro's BasicATOM chip as my solution.

An electronic drag race finish gate will be the project this month, along with a demonstration of how to use a very simple setup to program a BasicATOM chip.

BASICATOM CHIP

For those not familiar with the BasicATOM family of parts, they include three different chips: the BasicATOM28A, the BasicATOM28B, and the BasicATOM40. They are based on the PIC16F876A (BasicATOM28A,B) and PIC16F877A (BasicATOM40). They also are available in module form, similar to Parallax's BASIC Stamp, with programming interface circuitry and a voltage regulator built into the module circuit board. These modules are all surface mount so they can fit in a small package, but I prefer to work with leaded components so I can build it on a breadboard and easily replace parts if I fry something. It's also cheaper to use the chips rather than pay for the regulator and programming interface on every project.

My Ultimate OEM module and BasicBoard module use the leaded versions of the chip, but that again may be more than the beginner is willing to invest to get started programming. The truth is, the modules just make it easier to use the BasicATOM chips. All you really need to use the BasicATOMs are a 5V source and an RS-232 PC serial connection to program the BasicATOM chip.

■ FIGURE 1. Hot Wheels drag race.

For the drag race finish gate, I'm going to use the BasicATOM28B chip which is the same one I use in the Ultimate OEM module. The finished setup is shown in Figure 1. The schematic for the setup is shown in Figure 2. The BasicATOM28B and BasicATOM40 both use one pin to communicate with the PC. That single pin does both the Tx and Rx function, but requires a diode between them to make it work. A 10K pull-up resistor is also recommended on the single line after the diode. Basic Micro did this so it would only steal one I/O pin for programming and communicating back to the PC when running in Debug mode. The BasicATOM will allow you to step through your code command by command, so you can watch the variables change along with the internal registers within the chip. This is a great feature when you need to figure out why your code isn't doing what you expect.

The BasicATOM28A chip was the original and it uses two I/O pins for communicating and programming. This doesn't require a diode, but two 10K pull-up resistors are recommended. Therefore, you lose an I/O port, but still add two external components.

BASICATOM PROGRAMMING SETUP

The BasicATOM chip has a custom bootloader pre-programmed, in that it will download the program from the PC to its own internal program memory. It does this through the BasicATOM compiler, which actually produces a hidden .hex binary file similar to any compiler, such as microEngineering Labs' PICBASIC PRO compiler or even Basic Micro's own MBasic compiler. In fact, the BasicATOM software is a custom version of their MBasic Professional compiler that is limited to

■ FIGURE 2. Schematic for electronic Hot Wheels drag race system.

the BasicATOM chips. After writing your code, you simply click the Program button in the BasicATOM IDE screen and the software will compile the Basic language code, produce a .hex file with the binary ones and zeros, and send it to the BasicATOM chip through the PC's RS-232 port and into the BasicATOM chip via the bootloader. The BasicATOM chip will receive the .hex file and write its own program memory. (The program will start running as soon as the download is complete.)

You can't just connect the BasicATOM chip to the PC serial port, though. The communication between the BasicATOM chip and the PC requires a level-shifter circuit to convert the +12V, -12V RS-232 signals into the 0V, 5V signals the BasicATOM chip can work with. There are various RS-232 converter modules available on the Internet, but most don't include all the necessary connections required for the BasicATOM. Most of these modules only have the Tx and Rx pins. The BasicATOM software also uses the DTR pin of the serial port to put the BasicATOM chip into programming mode/run mode. Just having a reset button won't work.
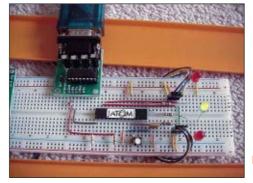
I designed my RS-232 breadboard interface module to include the reset feature, since I also use it with various bootloaders that will automatically reset the micro. I use this setup with the PICBASIC PRO compiler and microEngineering Labs' MicroCode

Studio Plus bootloader. The RS-232 module makes it real easy to connect the PC to a BasicATOM chip with just a couple of simple connections, as described earlier. The BasicATOM will also work with the USB port if you use an RS-232-to-USB converter cable. The schematic shows the connections, so you can wire it up with discrete components in place of my RS-232 module. In Figure 3, you can see the BasicATOM28B chip, along with the wired up RS-232 breadboard module.

SENSORS
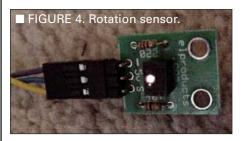
I wanted to make my system non-contact so it would not interfere with the Hot Wheels cars racing down the track. One of the changes they made to the classic track was to add holes at both ends of the flat part. These are there for custom track connectors, but when the track ended up on flat ground, they weren't used. I decided to find a sensor to fit in that hole. At first, I thought about using a CdS cell, but that would require a separate light source to shine from above. Then I remembered my servo sensor design which I used to monitor rotation of a robotic wheel (see Figure 4). It uses a QRD1114 reflective sensor.

■ FIGURE 3. BasicATOM28 chip and RS-232 breadboard module.

■ FIGURE 4. Rotation sensor.

■ FIGURE 5. The victory sensor.
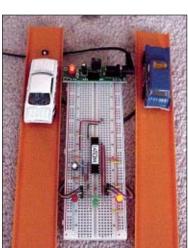
These sensors have an LED and light detector combined in one package. The LED sends a beam of light out, and the sensor picks up the reflection if something other than a black object is in front of it. I developed a little module that simply powers the LED and adds a pull-up resistor to the output. When the sensor sees black or no reflection, the output is high. When the sensor sees white or a reflection, the output goes low. I decided to make the hole in the track a little larger, so one of these sensors could be placed in each track (Figure 5). A close-up shot of the finished setup is shown in Figure 6.

After a quick test of running a couple of cars down the track proved the sensors did indeed sense when the Hot Wheels cars passed over, I now had to connect them to the BasicATOM chip and write the software to determine which one saw the car in its lane first. I decided to just have the BasicATOM light an LED on the left or right to indicate which side won the drag race. The hardest parts, in my mind, were reading the sensors at the same time, deciding if there was a car sensed, and then which one won — and do it all within the very short period of time when the cars passed over. As it turned out, the BasicATOM handled the challenge just fine. I also wrote the software to capture the state of the sensors, to give the program more time to sort out the winner.

HARDWARE

The hardware is a combination of what I already described, plus a little bit more. The BasicATOM chip programming setup, as described, plus the QRD1114 sensors connected to Port B pins P5 and P6, make up most of the circuit. The reset of Port B is left unconnected, but could be added to additional sensors for more lanes, if needed. In the software, I enabled the internal pull-up resistors on Port B so that all of the Port B pins will

■ FIGURE 6. The finished setup.

see a high when no car is sensed. If one of the sensors sees a car, then either the P5 or P6 input will go low. This makes the software easier, since all the program needs to look for is Port B to drop below FF hex (or 11111111 in binary) then jump to the section of code that determines which car won. (I'll cover more on that later in the software description.)

The LEDs that indicate which lane won are just lit through a 1K resistor. The extra LED is used to indicate whether the setup is armed and ready to look for a winner.

I used one of my breadboard 5V regulators to power the rails of the breadboard, but any 5V source will work. The BasicATOM needs a 20 MHz resonator and a typical MCLR pull-up resistor, which has a 4.7K value. The transmit line requires a 10K pull-up, and the diode is needed for the BasicATOM28B chip — as described earlier. The reset line from the RS-232 module connects to the MCLR pin. So, if you add it up, the BasicATOM chip only needs two additional connections — Tx and Reset — to program the chip, since the rest will be required for the circuit to work. If you use the BasicATOM28A chip, you'll need three connections (Rx, Tx, and Reset). The advantage to this setup is that the RS-232 module can move from board to board, and all you need is a different BasicATOM chip on each design. This is cheaper than buying modules.

The QRD1114 sensors are connected through servo extension cables, and then through a header into the breadboard. The re-arm switch is tied to Port C1, which requires a pull-up resistor — so I used a 10K. This way, the switch is pulled high until it's time to re-arm the setup. The armed and ready LED is connected to Port C0 through a 1K resistor.

That's it. This is a very simple circuit, because the complexity is in the software. Or is it?

SOFTWARE LISTING

How It Works

The software starts off by enabling the internal pull-ups on Port B. This is the only port on the BasicATOM28B chip (PIC16F876A) that offers this feature. The ports also have to be in input mode for the setting to take effect. That is the next port-control instruction where the TRIS register for Port B is set to all 1s making all the Port B pins inputs. In between these two commands, the "stat" variable is created. (The full software listing is available on the *Nuts & Volts* website at **www.nutsvolts.com**.)

```
setpullups pu_on        'PortB Pullups On
stat var byte           'Create variable status
trisb = %11111111       'RB6 and RB7 input, Rest of
                        ' PORTB Outputs
```

The main loop is the next section. The armed and ready LED connected to the C0 pin is set high. The BasicATOM software has predefined nicknames set for the port pins. Port B is P0 through P7; Port C is P8 through P15.

```
main
    high p8     ' LED On indicating Armed and ready
```

The value of Port B is captured and stored in the variable "stat." The signals at Port B will change quickly, so capturing and storing the value in a variable allows the rest of the program more time to read and respond to the results.

```
    stat = portb        ' The value of PortB is captured
```

All of Port B is set to inputs, with the pull-up resistors turned on — so Port B should look like all ones if nothing is connected. The sensor modules pull the line low when a car is sensed, so when sitting idle those inputs look like ones, also. Therefore, this command just looks for a value less than $FF hex (or %11111111 binary) to determine if a car has passed by. If nothing is sensed, it loops back to the main label and then checks again.

```
if stat = $FF then main    'Test for Car, loop
                           ' back if not sensed
```

If a value less that $FF is detected, the program checks which bit changed — indicating which lane won. If the value is 223 decimal or binary %11011111, then the right lane sensor was tripped. The right LED is turned on and the left is turned off. Then the program jumps to the wait label.

```
if stat = 223 then  'Test if Right Lane won
    high 12         ' Right LED on
    low 13          ' Left LED off
    goto wait       ' Jump to reset loop
```

If the right lane was not tripped, then the program tests the left lane bit. It would equal 191 decimal or %10111111 binary, if the left lane sensor was tripped. If this happens, then the left LED is turned on and the right one turned off.

```
elseif stat = 191   'Test if Left Lane won
    high 13         ' Left LED on
    low 12          ' Right LED off
    goto wait       ' Jump to reset loop
```

The final step of the If-Then-Else command is the "else" section. If both bits were tripped or a strange result was seen, then both LEDs light to indicate a tie or something wrong. Either way, the race must be run again to determine a winner.

```
else
    high 12         ' Tie
    high 13         ' Light both LEDs
    goto wait       ' Test again

endif
```

The last section in the program starts at the wait label. The first thing that happens is the armed LED is cleared, and then the program goes into a loop. It tests whether Port C1 — or P9 in BasicATOM nicknames — is low. A low indicates that the re-arm switch was pressed. If the switch isn't pressed, the port stays high because of the 10K pull-up resistor shown in the schematic. When the switch is pressed, the program clears the winning lane's LED, and the program jumps back to the main label to wait for the next race.

```
wait
    low p8                  ' Armed LED off
    if in9 = 1 then wait    ' Wait for rearmed
                            ' switch press
    low 12                  ' Reset LEDs
    low 13
goto main
```

NEXT STEPS

There are many ways that this program can be expanded. More lanes could easily be added, which would be tough for a mechanical system. I also want to add timing, so each lane's time is displayed on an LCD screen. This will take a little more strategy in the way the program responds to a sensor signal, though. A timer value has to be captured for each lane. Another point is, the sensors that I used rely on the bottom of the car to be reflective. As long as the bottom wasn't black, it seemed to work fine. But one of the cars tested was all black on the bottom. A sensor above the cars would have probably worked, but I had enough cars to test so it wasn't a big deal to throw that car out of the pack, for now. Possibly a better sensing method would be worth pursuing.

I also would like to add an automatic launch system, so a button could be pressed and then some kind of motor or solenoid would release the cars automatically. This will probably be part of another article. Feel free to try these ideas out yourself and email me your results. I can always be reached at chuck@elproducts.com.

CONCLUSION

Projects like this are really important to me, even though it may seem simple or rather dumb to someone looking for more complex applications. I feel projects like this are important because anyone can understand the benefits of adding electronics over the mechanical method in a simple toy setup like this. It may not be a cheaper solution, but to someone who is trying to learn programming, it's projects like this that make a connection. Show a complex project to a kid, and he may be amazed at what you did, but deep down not have a clue what you are talking about. But, show a kid something like this and they fully understand what you did. That could be the connection that gets them interested in electronics, or technology in general.

I'm not claiming I made that connection happen, but maybe a few readers will try this and some kids will see it and down the road want to learn programming, as well. That is worth far more to me than creating some complex programming algorithm. Take it further by laying out a board and turn it into a kit. This could be a great project for a Boy Scout troop or science fair demonstration.

I also wanted to mention that in August, Microchip is having its annual Masters Conference. It's a three to five day affair with loads of classes that teach everything from Ethernet to C Programming to just learning about the various PIC® microcontrollers. I'll be there as part of the Microchip team. If you attend, look me up. It's well worth the cost. If you need development tools, attendees

can purchase these for half price. As always, give me your feedback at chuck@elproducts.com or visit my website at **www.elproducts.com**. I have the BasicATOM chips, RS-232 modules, 5V regulator modules, and breadboards in stock if you want to reproduce the setup. The servo sensors are an item I've had on the shelf for a while, but haven't added them to the website, yet. Guess I need to get to that. See you next month! **NV**

CONTACT THE AUTHOR
■ Chuck Hellebuyck can be reached at **chuck@elproducts.com**

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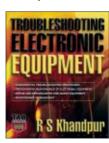
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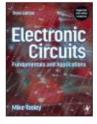
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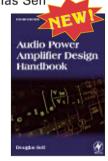
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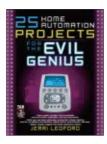
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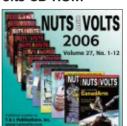
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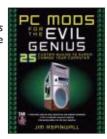
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TECH FORUM

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All questions *AND* answers are submitted by *Nuts & Volts* readers and are intended to promote the exchange of ideas and provide assistance for solving problems of a technical nature. Questions are subject to editing and will be published on a space available basis if deemed suitable by the publisher. Answers are submitted by readers and **NO GUARANTEES WHATSOEVER** are made by the publisher. The implementation of any answer printed in this column may require varying degrees of technical experience and should only be attempted by qualified individuals. Always use common sense and good judgement!

>>> QUESTIONS

I want to run a 24 VAC camera off of a 12 VDC battery. It is rated 6W at 24 VAC. What would be the easiest way to do this?

#7071   **David Fry**
via email

I would like to read a barcode attached to the bottom of a Model Railroad Car (HO Scale). This is to sense location on the track. The barcode would be read as the car passes over the reader. Multiple readers would allow a computer to track train progress on a large layout (14' x 204').

Does anyone know of a method/sensor to read barcodes? The sensor would be similar to a wand but with a .75" read range.

#7072   **Dave Moore**
via email

I'm trying to program an old LED sign built by Mitchum Sign Works in 1985. The electronic sign still functions, but I have no idea how to program its message. The lithium battery to retain the volatile memory has long since died, but the UV PROMs still run a powerup message.

The only marking on the main board is "PC101 Rev. B." It has a Zilog Z80A CPU and an INS8250 UART to control the serial port. The display has a serial port I presume for programming, but I haven't figured out any combination of baud, parity, stop bits, and character sequences to get the display to communicate.

Any information would be much appreciated.

#7073   **Aaron Jahnke**
Maryland Heights, MO

I am a novice when it comes to solar cells. I recently bought six solar cells and started playing with them. I noticed that even though these solar cells are from the same company and the same make, they produce different outputs. I was wondering if this was normal? Also, when I connected two cells together in parallel, if I did not put a diode in series with the cells for each cell, I would get a lower value than the two cells divided by two {(Cell1 + Cell2)/2}. I was not expecting this result.

Could someone please shed some light on this? Do you always need to use a diode in parallel with each cell when trying to build up the amperage? I guess it goes without saying that you only need one diode in series with two cells in series for greater voltages.

Background: If you test the cells by themselves (open circuit), four of these solar cells are producing 15 to 17 VDC with two only producing eight volts.

The short circuit current is .100 amps to .140 amps.

Also, could you explain how to choose a solar cell for a project? I understand if I am running 4X 12V fans at 100 mA, I would add up the total amps: 400 mA for the project. But what I am seeing from my meter is my voltage drop is a lot lower than what I would expect for a parallel circuit. Do I need to add a capacitor or something?

#7074 **DW**
via email

Can someone recommend a 12-14 volt circuit which will give a three second duration "high" output of around 5-6 volts (not critical) after 12-14 volts power has been applied to the input for 15 minutes? The "high" output will last three seconds (to activate a very small relay or transistor) and then go back low for 15 minutes over and over. In other words, the relay will pull in for three seconds every 15 minutes.

#7075 **Jerry Roberts**
via email

I can purchase a DC motor speed controller for a 1.5 HP motor for my Bridgeport mill, or an inverter duty AC motor and controller, too. What are the advantages to both of these setups and why were they made in the first place?

#7076 **via email**

I need info on where to buy or how to build a cheap mono preamp for my banjo. I need more drive into my amp.

#7077 **O. Robert Lawrence**
North Bay, Ontario

>>> ANSWERS

[#2074 - February 2007]
I'm looking for a YDA135 sound processor chip, but cannot find a supplier to purchase a few.

The chip, YDA135, is manufactured by Yamaha. The website with the information on the chip is: **www. yamaha.co.jp/english/product/lsi/ digital/lineup/yda135.html**

You could try and contact them directly to first see if they could supply the chip or see who they supply this chip to. Check with the larger suppliers online such as Mouser Electronics, Jameco, or Digi-Key to see if they have it or if they could special-order it from Yamaha.

Ralph J. Kurtz, N3KOL
Old Forge, PA

[#3071 - March 2007]
I have a symphonic SL 2940 VCR that I would like to use as a security component with a camera and motion sensor to record for five to 10 minutes as motion is sensed and repeat, if necessary.

This mob sells a kit for AUD$25 plus shipping: **http://secure.oatley electronics.com//product_info.php? cPath=26_71&products_id=212&os Csid=438e110c8cf4211e7443a6f4a5 b84fce**
but ...
There was a similar circuit published in an article in one of two magazines in Australia. The magazines are either *Electronics Australia* (now defunct, but you may find info online) and *Silicon Chip* (this mob was going to archive the articles of the other mag).

Al Boyd
via email

[#3075 - March 2007]
Can electrolytic capacitors be used in a voltage divider circuit to provide about 24 volts AC to a heater cable from the 120 volt AC line?

First of all, electrolytic capacitors should (almost) never be used on AC mains power circuits. They WILL explode within three alternations, or well within one second. The larger the cap, the bigger the pop. Even if you aren't injured or start a fire, there will be caustic electrolyte deposited everywhere in the area. This is due to their polarity, and the same applies to tantalum caps also. They can't take the reverse alternations of AC.

Nonpolarized electrolytic caps (or two regular ones wired back-to-back in series) do find occasional use, most-

ly in audio circuits and cross-over networks, but that is a far cry from the type of single frequency, high current usage you propose for a heater circuit.

For rectified DC voltages, a stack of (usually two) electrolytic caps is sometimes seen, usually to simulate an artificial ground for bipolar analog circuits, but they rarely work well for this due to uneven dropping of the voltages (notice that most electrolytic caps have a 20% tolerance). That, coupled with uneven ESR values, mean that much tweaking is required to get accurate voltage divider dropping even in DC circuits. The reason I bring this up is to answer your point about parallel stacking of capacitors. Being reactive rather than resistive components, capacitors DO NOT dissipate heat in the same way that resistors, light bulbs, and other heating elements do. Placing caps in parallel increases their overall capacitance, but does not augment their voltage rating or their ability to manage heat issues. Ideally, there should be no heat to dissipate, only stored and returned electron charge.

Series-stacked nonpolarized capacitors — mostly ceramic — are sometimes used as voltage dividers in high voltage DC circuits, but there is rarely much current involved here. The only instance where nonpolarized caps are used to drop significant amounts of AC voltage directly (as you want) are the use of a single series-connected metallized polypropylene cap. These range in value from about 0.1 to about 6.8 µF, and choosing a proper value at 60 Hz can allow you to drop 120 VAC down to 6-50 VAC, but again only with a maximum current in the low tens of mA level; not what you need for a heater. Additionally, this reduced voltage is not an isolated voltage source, and additional precautions must be observed to prevent a shock hazard between this line and earth ground.

After telling you all the bad news about why what you want to do probably won't work, the good news is there is an easy solution for you: 24 VAC high current heater circuits are downright easy to build using a step-down power transformer. If there

was ever a time to use a transformer, this is it. They are relatively inexpensive — depending on your heater current needs — and provide clean, isolated AC without the power loss associated with current-dropping resistors. Another idea — depending on how much heating you need to do and whether your heating cable is flexible in its design — is to connect five heater strings in series and run the whole network directly from 120 VAC.

Paul Chaney
La Habra, CA

[#3076 - March 2007]
My 1989 mini van has developed a static whine in the radio. The higher the RPM, the louder the whine. Is there a circuit to filter out the noise?

#1 Before you start with filtering out the whine in your car AM radio, it will be best to find out why it started.

The source of such whine usually is your car's alternator and rectifier; there usually is a small capacitor to cut the AC whine; also, the car battery should be close and its capacitance helps to filter the AC whine.

I would first look at the antenna shielded cable and its connection to the radio case. If corroded, the cable/radio junction will receive all interference which becomes stronger than what comes from your antenna whip. The best cure — if cleaning does not help — is to replace the cable completely.

Also, the DC power connection to your radio may need some cleaning of the contacts, mainly the ground connection to the car chassis. If all of the above fails, try to connect a small electrolytic capacitor across the DC power connection; be sure the negative terminal comes to ground.

JIri Polivka
Santa Barbara, CA

#2 While less prevalent today than in earlier vintage cars (mostly due to electronic rather than mechanical points ignition systems), hum and noise can still develop in car radio systems. A whine sound with a higher pitch as RPM increases is typically caused by the alternator, although

there are other causes, as well.

The typical solution is an L or pi low pass passive filter consisting of a high value choke (>1 mH) that is placed inline with the B+ radio power wire, as close to the radio as possible, along with one or two low value (0.1-5 µF) bypass capacitors that are soldered (near the inductor) between the B+ and ground wire. RadioShack used to sell choke/capacitor kits that were ready-made for this purpose, but a search of their website turned up nothing, so they may be discontinued. These kits may be available at your local auto parts or stereo shop. One source is PartsExpress (**www.parts express.com**), who sells a 10 amp kit (part #265-042) for $3.90.

This may very well mask your problem, but not solve it. Since you have an auto with nearly 20 years of "experience," you should look at this as a symptom, especially if it either suddenly occurred or slowly developed over several months, as both are good clues to the cause. A shorted or open rectifier diode in the alternator will suddenly cause this problem, as will a break in the rubber insulation on one of your spark plug wires. This allows the spark to bypass the plug and short to the engine block, generating noise and also robbing you of engine power.

An example of a slowly developing whine occurs when the filter capacitors inside the radio begin to dry out, causing formerly acceptable amounts of line noise to become audible. Either way, you should have your van serviced to ensure that the radio noise is not just the tip of the iceberg.

Paul Chaney
La Habra, CA

[#4071 - April 2007]
Can I hook up a Velleman K4003 amplifier to my speakers directly to increase volume and what does the circuit wiring entail?

The information sheet that is available at the Velleman website for this amplifier (K4003) shows that it is possible to connect the amplifier to the two speakers. For the wiring diagram and connections, you should

check this information sheet that can be downloaded at **www.vellemanusa. com/downloads/0/infosheet_k4003_ connection.pdf**

In addition to the speakers, you will have to supply the voltage transformers for 12 volts with a current rating of 2A.

You did not specify what the impedance of the speakers is. The power delivered to the speakers is dependent on their impedance as shown in the instructions manual: **www.vellemanusa.com/downloads /0/illustrated/illustrated_assembly _manual_k4003_rev1.pdf**

If you have to purchase the speakers, you should select them for the power that you want delivered. If you already have them, the power will depend on their impedance as shown in the manual linked above.

Albert Lozano
Edwardsville, PA

[#4072 - April 2007]
I want to build a battery charger that can continuously charge a battery under load — such as you would find in an online UPS.

I'm not sure how this would differ from a regular continuous maintenance charger (i.e., a charger that supplies a trickle charge, as well as periodic higher power plate cleaning charges).

You say that you want to charge a battery while it is supplying current to a load. This is not possible, as you can't have current coming out of a battery to power a load, and at the same time, have current going in to charge it. Current flows in only one direction. If a load is connected across a battery in parallel with a charger with enough capacity to charge the battery, then the charger itself would be powering the load, not the battery. You can't simply put a trickle charger across a battery under load as you suggest.

You mention the example of the battery in an online UPS. The output of a DC power supply in the online UPS connects to a DC-to-AC inverter and to the battery in parallel. The load connects to the simulated sinewave

output of the inverter, which operates continuously when the power switch is on. The DC supply voltage powers the inverter and keeps the battery charged. Only when the utility AC power fails is the battery under load as it supplies power to the inverter. If the UPS power switch is off, the inverter is turned off, and the power supply remains energized and keeps the battery charged as long as the UPS is plugged in.

Marvin Smith
Harbor City, CA

[#3073 - March 2007]

I am working with the very old, MS-Basic Interpreter. It is limited to 16 digits in double-precision mode. If I try to multiply two 15-digit numbers, it slips into "Exponential Notation" mode: example 2.43E+06. Thus, a 15-digit number TIMES another 15-digit number would have a 30-digit product. Is there a way to convert — in MS-Basic — this "Exponential Notation" into all 30 digits?

To do the math in MS Basic with huge numbers, you need to know at least how to do the math on a blackboard, especially the multiplication and long division. Scientific or exponential notation or "floating point" does not calculate very many digits of large numbers, mainly because they aren't often needed for most practical uses. So you must program subroutines to do the arithmetic at least the blackboard way, or look up algorithms (but it may be hard to find

them in Basic). Here are a few ideas to start:

1. You can use strings to hold numbers up to 255 digits and access each digit using the MID$ command.

```
10 A$="10485764545454545454545454545":B$="12345"
20 GOSUB 3000:REM MULTIPLY
30 PRINT C$
```

2. You can use arrays to store numbers, but it's slower and wastes memory, and makes it harder to enter numbers.

Example: For up to 100 digit numbers, one array element per digit defined as:

```
10 DIM A(100),B(100),C(100),D(100)
```

3. You can reserve a large area of memory as a virtual blackboard using the CLEAR command, and store, access, and process digits of numbers using POKE and PEEK within the reserved space.

That way, you can easily (but slowly) work with many thousands of digits. It's recommended to compile or assemble the finished subroutines into machine language for speed, especially when this method is used. Handling decimal points will be an extra challenge, but it won't make much difference whether you use remainders or decimal points in division. It depends on whether you learned them in school. Here is an example of addition in the method using arrays, without handling decimal points:

```
1000 REM ADD A() TO B(B) AND PUT INTO C()
1010 X=0:C=0:REM X is digit number and C is carry
1020 C(X)=A(X)+B(X)+C:IF C(X)<10 THEN 1040:REM NO CARRY
1030 C=1:C(X)=C(X)-10:X=X+1:GOTO 1020:REM CARRY
1040 C=0:X=X+1:IF X<=100 THEN 1020:REM DO 100 DIGITS
1050 RETURN:REM IT'S DONE
```

It is possible for this to overflow if the answer is too high. And it's necessary to fill the arrays with zeroes before putting new numbers into them. Also, the numbers should be printed out starting at the highest digit which is not a zero, with the C(1) and C(0) being the last digits printed.

Working with strings makes the most sense in general but the example would be more confusing involving MID$,ASC,VAL,STR$,LEN,LEFT$,RIGHT$,CHR$, etc. The POKE and PEEK method is the most powerful in number size and works similar to the array method.

William Como
Bethpage, NY

[#5073 - May 2007]

I need a source for 365 variable capacitors which RadioShack used to sell as catalog number 272-1431 and used to be incorporated in their Science Fair kits — I've tried eBay but the sellers want too much for it!.

Alas, RadioShack has discontinued the variable capacitor, but one can find a substitute from Graymark International. They have an AM Radio kit, Model 536, that uses a similar capacitor, it is a dual section, ant & osc, but same size. Their P/N is 62714; cost was around $2.

This will require a tuning knob, not included, their P/N 62705; another quarter or so. I used the kit in teaching a radio class, it is a REAL good training tool. Good radio, too.

Rod Hogg
Scott City, KS

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